Strategic Considerations for Support of Humans in Space and Moon/Mars Exploration Missions

Life Sciences Research and Technology Programs



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Strategic Considerations for Support of Humans in Space and Moon/Mars Exploration Missions

Life Sciences Research and Technology Programs

VOLUME II

NASA Advisory Council Aerospace Medicine Advisory Committee

June 1992

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Strategic Considerations for Support of Humans in Space and Moon/Mars Exploration Missions

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CHART 1
PERCENTAGE OF CRITICAL QUESTIONS IN CONSTRAINED* AND ROBUST** PROGRAMS

| Categories | 3 | Criticality | | |
|---|-----------------|-------------|-------|-------|
| | ** | 3 | 4 | TOTAL |
| Environmental Health & Life Support | 3.7% to 7% | %2.6 | %6:0 | 27.0% |
| Countermeasure Validation | **** 10.5* | 14.4% | 5.8% | 31.8% |
| Medical Care | 25% 2.5% | 2.1% | %0.0 | 7.1% |
| Total Moon/Mars Exploration *** | 784 | 26.2% | 6.7% | 65.9% |
| Enabled Science | voe voe | %0.9 | 2.8% | 11.8% |
| Non-Exploration Science | NOS SOS | %0.0 | 22.2% | 22.2% |
| Total Enabled and Non-Exploration Science | Service Service | 6.0% | 28.0% | 34.0% |
| Grand Total | 7.6% 85.4% | 32.2% | 34.7% | 99.9% |

* Constrained Program = Criticality 1 and 2

** Robust Program = Criticality 1, 2, 3, 4

*** 88% of Criticality 1 and 2 deliverables are required for the Moon Base. *** The level of refinement and complexity for the Moon Base would be significantly less than for Mars exploration

- Deliverables

- Milestones

- Platforms (Ground and Filight)

CHART 2
EXECUTIVE COMMITTEE and AMAC DISPOSITION OF CRITICAL QUESTIONS
FOR CONSTRAINED* AND ROBUST** PROGRAMS

| Environmental Health & Life Support 16 km 18 km 19 km | Criticality Criticality Criticality 3 1 2 2 1 2 3 1 1 1 1 1 1 1 1 1 1 1 1 1 | 4 TOTA 1 3 1 1 1 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | Catag | 177 1 1 1 | Committees icality 3 4 TOT | XXX F | Criticality | 4 | TOTAL |
|---|---|--|-------------|---------------|----------------------------|--------|-------------|-------|----------|
| SB Staff X | Criticality | | | Oriticality 3 | 4 | XX * | | 4 | TOTAL |
| Physiology | J <u>_ </u> | ╣╺╌┠╶┠╌╂╌╏╶╏╌╏ ╌╏ | w | | - | | | • | |
| Physiology | | - | ** 10 ** 4 | | | • | | | |
| Physiology 2 2 2 2 2 2 2 2 2 | | ┈╏┈╏┈╏┈╏┈╏┈╏ | 10 vr 40 | | | | | _ | e |
| New Health | | ┍┈┡┈╏┈╏┈╏┈╏ ┈╏ | 100 vr 40 | | - | × | | - | |
| Note Health | | | 30 vr - 40 | | _ | × | | | 0 |
| Per Per | | | * 8 | - | \vdash | 13 K | * | - | ٦ |
| March Marc | | | es . | | \vdash | * | | - | <u>'</u> |
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| Protection | | 6 | 2000 - C | - | 1 | 2 0 | | | 2 8 |
| ### 135 % ### ### ### ### ### ### ### ### ### | | | | L | $\frac{1}{1}$ | | | - | 3 |
| ### Principle | | 0 | Ļ | | H | | | _ | 1 |
| ### Validation 34 2 2 | 1 | | 0.0 | 5 | 6 | | | 4.2 | , |
| Physiology 2.5 km 2.5 km | | 3 | 0000 Page 1 | 1 |] | | *** | | |
| Physiology 2.5 | 4 | 35 | 7 | 13 | _ | | | 14 | 30 |
| Ital Health | | 7 163 | | | L | | | | 24 |
| Ital Health | 7 | 9 | | | L | | * | | |
| See 13 14 15 15 15 15 15 15 15 | | | | l | + | - | , | • | 2 - |
| 13 2 2 2 2 2 2 2 2 2 | 10 | | ۲ | 1.0 | ļ. | | | • | - 6 |
| ### Partial Biology 2.5 k 12 k 1 | L | 2 18 | | 1 | L | l. | | 2 1 | 36 |
| Of velopmental Biology 2.5 k 1.2 k 1 totaction x x 2 counter Measures x x 3 counter Measures x x 4 counter Measures x x 5 counter Measures x x 6 counter Measures x x 7 counter Measures x x 8 counter Measures x x 9 counter Measures x x 148 k x x 8 counter Measures x x 148 k x | L | | | • | L | | ı | • | 1 |
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| Physiology 51 X 30 X 8 | 200 | | | 7 9 | , | | | ľ | 2 |
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| elopmental Biology 3 | 2 | 13 | ľ | ~ | | | ľ | | Ī |
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| Life Support | | | | | - | | | | • |
| Protection | | 0 | | L | - | | | | } |
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| 122 | 126 | 30 268 | • | | | | 2 . | | , ; |

*Constrained Program = Criticality 1 and 2 **Robust Program = Criticality 1,2,3,4 Page 1

CHART 2

EXECUTIVE COMMITTEE and AMAC DISPOSITION OF CRITICAL QUESTIONS
FOR CONSTRAINED* AND ROBUST** PROGRAMS

| Catagories and Disciplines | DWGs | | | E | 5 | STEER | EXECUTIVE STEEPING COMMITTEE | AMITE | | | × | | • | AMAC | | - |
|--|-------|-------|--------------|----------|-----------------------|--------------|------------------------------|---------------------|-------------|----------|-------|----------|-----|-------------|--------------|---------|
| | | | Halasi | Co | Discipline Committees | × | õ | Category Committees | Com | nittees | × | | | | | |
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| | | | | <u>8</u> | • | і Ітота¶Ж | 7 | ** | | <u>추</u> | TAL | 7 | ~ | <u>e</u> | | 4 TOTAL |
| Enabled Science | | | | - | - | | L | - | - | - | 3 | _ | - | <u> </u> | , | • |
| Behavior Performance and Human Factors | * | 0007 | | | - | × - | | 1 | 1 | ╡ | - | | † | † | † | -[|
| Regulatory Physiology | 2 🗶 | 302 | | - | - | 2 | | | = | 7 | 7 | | | + | - - | 7 |
| Cardiopulmonary | 2 | 2200 | | 2 | 8 | 10 | | | ~ | 8 | 10 | | 1 | ~ | * | 2 |
| Environmental Health | | × | | | | 0 | | 1 | 1 | + | • | | 1 | † | † | 1 |
| Musculoskeletal | | | | | | 0 | | 1 | 1 | = | - | | Ī | † | - 6 | -[|
| Neurosciences | 4 | | | | 6 | 6 | | | | 6 | 0 | | 1 | 1 | 5 | 1 |
| Badiation Health | | | | | | ٥ | | | 1 | + | 9 | | 1 | 1 | \dagger | ° |
| Distriction of the Control of the Co | | | | | | 0 | - | | | | • | | 1 | 1 | 1 | 2 |
| Call and Developmental Biology | , | | | | | 0 | | | | 2 | 5 | 888 | | | 2 | • |
| Cell and Developmental Chargy | | *** | | | | ° | | | | | 0 | *** | | 1 | 1 | • |
| Cine Support | | | L | | Ī | 0 | | | | Н | 0 | *** | | 1 | 1 | ٥ |
| Planetary Protection | 9, | | | 23 | Ī | 23 | | | 23 | - | 23 | *** | | 23 | | 23 |
| Exobiology | 0 | l | ľ | l | ۶ | | 6 | 0 | 26 | 25 | 51× | 0 | 0 | 26 | 2.5 | 51 |
| Total | 000 | | | ╛ | | | | | | | | | | | | |
| Non-Exploration Science | ** | 3 | _ | | | * | 3000 | | _ | _ | 0 | * | | | | 0 |
| Behavior, Performance and Human Factors | | | 1 | | | 7 | | | T | | 13 | * | | | 28 | 28 |
| Regulatory Physiology | | | | | | 1 | | Ī | T | T | ٦ | | | | - | 0 |
| Cardiopulmonary | | -34 | 1 | | | Ĭ | | | T | T | 0 | | | | | ٥ |
| Erwironmental Health | | | 1 | | | Ť | | | T | t | 6 | | | | | ٥ |
| Musculoskeletal | | | | | | | | | T | T | | *** | | | 8 | 3 |
| Neurosciences | | | 1 | | | Ť. | | | T | T | ٦ | | | | | 0 |
| Radiation Health | - T | ~% | 1 | | | - : | | | T | T | 4 | | | | 56 | 56 |
| Cell and Developmental Biology | | | \downarrow | | | * * | | | T | T | - | | | | | ٥ |
| Plant Biology | 6 | | - | | | | | | ľ | | ٦ | | | | | P |
| Life Support | | | 1 | | | | 2783 | | 1 | 1 | 1 | | | | Ì | ٥ |
| Planetary Protection | | * | | | | | | | 1 | Ť | ٦ | | | | ٥ | 1 |
| Exobiology | | * | | | | 6 | | | 1 | ľ | on i | | ľ | ľ | 0 8 | |
| Total | 63 | × | | | | € 5 🗶 | ٥ | • | 힉 | 0 | - | ○ | 2 | 2 | \$ | P |
| | | *** | | | | *** | | - 1 | | | | | | ; | 1 | 00, |
| TOTAL ALL CRITICAL QUESTIONS | 200 | X 122 | 2 90 | 152 | 49 | 478 X | 40 | 144 | 137 | 7 | 446 X | 33 | 130 | 139 | 130 | 432 |
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CHART 3 Requirements for Ground-based Research and Flight Platforms For Constrained* and Robust** Programs

(Number of Critical Questions)

| Critical Questions Which Require R&A Behavior, Performance and Human Factors Regulatory Physiology Cardiopulmonary Environmental Health Musculoskeletal Neurosciences Radiation Health Cell and Developmental Biology Life Support Planetary Protection Exobiology Top Level Countermeasures Total Space Labs Behavior, Performance and Human Factors Regulatory Physiology Environmental Health Musculoskeletal 3 1 1 1 3 1 3 7 Space Labs Regulatory Physiology Cardiopulmonary Environmental Health Musculoskeletal Neurosciences Radiation Health Musculoskeletal Neurosciences Radiation Health Cell and Developmental Biology 1 2 3 2 4 7 Regulatory Physiology Regulatory | | 31 65 24 14 37 28 28 79 19 50 2 32 2 411 |
|--|--|---|
| Critical Questions Which Require R&A Behavior, Performance and Human Factors \$ 16 14 Regulatory Physiology 2 3 25 Cardiopulmonary 8 9 9 Environmental Health 9 1 Musculoskeletal 3 16 13 Neurosciences 1 5 7 Radiation Health 8 2 18 Cell and Developmental Biology 1 6 Plant Biology 5 3 Life Support 8 26 18 Planetary Protection 1 1 Exobiology 23 Top Level Countermeasures 2 2 Total 31 103 137 Space Labs 8 80 Behavior, Performance and Human Factors 8 18 9 Regulatory Physiology 2 3 24 Cardiopulmonary 2 5 9 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 7 | 35 6 3 15 2 62 6 9 140 | 65 24 14 37 28 26 79 19 50 2 32 2 411 |
| Behavior, Performance and Human Factors S 16 | 35 6 3 15 2 62 6 9 140 | 65 24 14 37 28 26 79 19 50 2 32 2 411 |
| Regulatory Physiology | 9 140 1 35 8 | 24 14 37 28 26 79 19 50 2 32 2 411 |
| Cardiopulmonary 8 9 Environmental Health 9 1 Musculoskeletal 3 18 13 Neurosciences 1 5 7 Radiation Health 6 2 18 Cell and Developmental Biology 13 6 Plant Biology 5 8 Life Support 8 26 18 Planetary Protection 1 1 Exobiology 23 23 Total 31 103 137 Space Labs 8 8 9 Regulatory Physiology 2 3 24 Cardiopulmonary 3 5 9 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 2 1 1 | 3 15 2 62 6 9 140 | 14 37 28 28 79 19 50 2 32 2 411 |
| Environmental Health | 15 2 62 6 9 140 1 35 8 | 37 28 28 79 19 50 2 32 2 411 |
| Musculoskeletal 3 18 13 Neurosciences 1 6 7 Radiation Health 2 18 18 Cell and Developmental Biology 13 6 Plant Biology 3 1 1 Life Support 3 26 18 Planetary Protection 1 1 1 Exobiology 23 23 23 Top Level Countermeasures 2 2 2 Total 31 103 137 Space Labs 8 8 9 Regulatory Physiology 2 3 24 Cardiopulmonary 2 3 24 Cardiopulmonary 3 8 8 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 2 1 | 15 2 62 6 9 140 1 35 8 | 28 28 79 19 50 2 32 2 411 |
| Neurosciences | 15 2 62 6 9 140 1 35 8 | 28 28 79 19 50 2 32 2 411 23 64 |
| Retirosciences | 2 62 6 9 140 | 28 79 19 50 2 32 2 411 |
| Cell and Developmental Biology | 9 140 1 35 8 | 79 19 50 2 32 2 411 |
| Plant Biology | 9 140 1 35 8 | 19 50 2 32 2 411 23 64 |
| Life Support \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ | 9 140 1 35 8 | 50 2 32 2 411 23 64 |
| Planetary Protection 1 | 140 1 35 8 | 2 32 2 411 23 64 |
| Exobiology 23 23 24 25 26 27 27 28 29 29 29 29 29 29 29 | 140 1 35 8 | 32 2 411 23 64 |
| Top Level Countermeasures 2 | 140 1 35 8 | 2 411 23 64 |
| Total 31 103 137 | 1 35 8 | 23 |
| Space Labs Separation Sep | 1 35 8 | 23 |
| Behavior, Performance and Human Factors 8 13 9 Regulatory Physiology 2 3 24 Cardiopulmonary 2 5 9 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 2 1 | 35 8 | 64 |
| Behavior, Performance and Human Factors 8 13 9 Regulatory Physiology 2 3 24 Cardiopulmonary 2 5 9 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 2 1 | 35 8 | 64 |
| Regulatory Physiology 2 3 24 Cardiopulmonary 2 5 9 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 2 1 1 | 8 | |
| Cardiopulmonary 2 5 9 Environmental Health 3 8 Musculoskeletal 3 17 12 Neurosciences 1 4 7 Radiation Health 2 1 1 | | 24 |
| Environmental Health 3 8 Musculoskeletal 3 1.7 1.2 Neurosciences 1 4 7 Radiation Health 2 1 | 3 | |
| Musculoskeletal 3 1.7 1.2 Neurosciences 1 4 7 Radiation Health 2 1 | 31 | 11 |
| Neurosciences \$ # 7 Radiation Health 2 1 | | 35 |
| Radiation Health | 15 | 27 |
| | | 3 |
| | 43 | 59 |
| Plant Biology | 6 | 19 |
| Life Support 2: 15 7 | - | 24 |
| Planetary Protection | - + | - i |
| Exobiology 2 | + | <u>÷</u> |
| Top Level Countermeasures | 112 | 292 |
| 1 0 cm | <u> </u> | |
| Behavior, Performance and Human Factors 5 14 | 2 | 34 |
| Regulatory Physiology 23 3 23 | 36 | 64 |
| Cardiopulmonary 8 6 9 | 4 | 22 |
| Environmental Health | | 14 |
| Musculoskejetal 91 18 13 | 3 | 37 |
| Neuroecianos 1 5: 7 | 16 | 29 |
| Radiation Health 1 | - 7 | $\frac{4}{20}$ |
| Plant Biology | 59 | $\frac{20}{75}$ |
| Cell and Developmental Biology 6 | - 59 | 45 |
| Life Support 5 25 15 | | $\frac{-\frac{43}{2}}{2}$ |
| Planetary Protection 1 5 | - 6 | 11 |
| Exoploid | | 2 |
| Top Level Countermeasures 27 132 97 | 133 | 359 |
| i Otal | • | |
| Centrifuge is required Behavior, Performance and Human Factors | 1 | 3 |
| Regulatory Physiology 2 3 18 | 20 | 43 |
| riegulatory / injurious) | 4 | 19 |
| Environmental Health 2 1 | | 3 |
| Musculoskeletal 5 13 | 2 | 36 |
| Neurosciences 1 4 4 | 12 | 21 |
| Radiation Health | | 1 |
| Cell and Developmental Biology 11 6 | 55 | 72 |
| Cell and Developmental Biology | 7 | 20 |
| Frant bloody | | 6 |
| Life Support | | 0 |
| Planetary Protection | | 0 |
| Exobiology 2 | | 2 |
| Top Level Countermeasures | 100 | |
| Total 9 3 3 4 | | |

CHART 3 Requirements for Ground-based Research and Flight Platforms For Constrained* and Robust** Programs

(Number of Critical Questions)

| | | С | ritical | itv | |
|---|------------------------|--|----------------|----------------|--------------|
| | • | | | • | тот |
| Free Flyer | B000000000000 | .00000-00000 | , , | • | , |
| Behavior, Performance and Human Factors | | | 1 | | _ 0 |
| Regulatory Physiology | | ****** | 1 | 5 | 8 |
| Cardiopulmonary | | **** ******************************** | 4 | 2 | 8 |
| Environmental Health Musculoskeletal ' | | ***** | | | 3 |
| | | | 5 | 2 | 12 |
| Neurosciences Radiation Health | | **** | 7 | 13 | 24 |
| Plant Biology | 3 | | 2 | | 4 |
| Cell and Developmental Biology | | ************************************** | | 2 | 5 |
| Life Support | | | 3 | 51 | 63 |
| Planetary Protection | | | 1 | | 1 2 |
| Exobiology | | | - ' | 1 | |
| Top Level Countermeasures | | | | 4 | 1 |
| Total | | | 2 | | 2 |
| Lunar Base | | 2.5 | 25 | 76 | 133 |
| | \$440000000000 | | | | |
| Behavior, Performance and Human Factors | | | 13 | 2 | 33 |
| Regulatory Physiology | 2 | | 15 | 28 | 47 |
| Cardiopulmonary | 3 | | 5 | 2 | 16 |
| Environmental Health | | 8 | 1 | | 13 |
| Musculoskeletal | 9 | | 12 | 2 | 31 |
| Neurosciences | | 000000000000 | | | |
| Radiation Health | _ | * | 7 | 12 | 25 |
| Cell and Developmental Biology | 8 | | _1 | | 4 |
| | | . 10 | 5 | 37 | 52 |
| Plant Biology | | | | 3 | 4 |
| Life Support | - 6 | 24 | 15 | | 45 |
| Planetary Protection | | | 1 | | 2 |
| Exobiology | | | 3 | 6 | 9 |
| Top Level Countermeasures | | | 2 | | 2 |
| Total | 2.6 | | 80 | 92 | 283 |
| Robotic Exploration | \$00000 000 | *********** | 001 | - 21 | 203 |
| Behavior, Performance and Human Factors | | 300000000 1 | 1] | 1 | _ |
| Regulatory Physiology | | - | ' - | | <u>2</u> |
| Cardiopulmonary | | | _ | | - 0 |
| Environmental Health | | ******* | -+ | | - |
| Musculoskeletal | | | | | - 0 |
| Neurosciences | | | | | 0 |
| Radiation Health | 2 | | | | 2 |
| Cell and Developmental Biology | | ************************************** | | | 1 |
| Plant Biology | | | | | 1 |
| Life Support | | ****** | | | 0 |
| Planetary Protection | | | 1 | | 2 |
| Exobiology | | | 20 | 5 | 25 |
| Total | | 2 | 22 | 5 | 33 |
| Other Flight Resources | | | - | • | |
| Behavior, Performance and Human Factors | | | 1 | - 1 | 0 |
| Regulatory Physiology | | | _ | | 0 |
| Cardiopulmonary | | | | \dashv | 0 |
| Environmental Health | | | | -+ | |
| Musculoskeletal | | | | | 0 |
| Neurosciences | | | | \dashv | 0 |
| | | | | $-\!\!\perp$ | 0 |
| Radiation Health | 2 | 2 | 2 | L | 6 |
| Cell and Developmental Biology | | | | | 0 |
| Plant Biology | | | | | 0 |
| Life Support | | | | | 0 |
| Planetary Protection | | | $\overline{}$ | + | -0 |
| Exobiology | | | | -+ | |
| Total | | | | _ + | 0 |
| 10001 | 2 | 2 | 2 | 0 | 6 |

CHART 3 Requirements for Ground-based Research and Flight Platforms For Constrained* and Robust** Programs

(Number of Critical Questions)

| | C | riticali | ty | |
|---|-----------------------------|----------|----|-----|
| | 1 1 2 | 3 | 4 | TOT |
| Facilities are insufficient | | | | |
| Behavior, Performance and Human Factors | 1 9 | 6 | 1 | 17 |
| Regulatory Physiology | | | 2 | 2 |
| Cardiopulmonary | | | | 0 |
| Environmental Health | | | | 0 |
| Musculoskeletal | | | 1 | 1 |
| Neurosciences | | | | 0 |
| Radiation Health | 4 4 | 16 | 2 | 26 |
| Cell and Developmental Biology | | 2 | 20 | 23 |
| Plant Biology | 13 | - | 7 | 20 |
| Life Support | 8 19 | 15 | | 37 |
| Planetary Protection | | 1 | | 2 |
| Exobiology | | | 6 | 6 |
| Top Level Countermeasures | | 2 | | 2 |
| Total | 9 48 | 42 | 39 | 136 |
| Science Community is Insufficient | E | | | |
| Behavior, Performance and Human Factors | 1 3 | 3 | | 7 |
| Regulatory Physiology | | | 2 | 2 |
| Cardiopulmonary | | | | 0 |
| Environmental Health | | | | 0 |
| Musculoskeletal | | | 1 | 1 |
| Neurosciences | | | | 0 |
| Radiation Health | | 1 | | 1 |
| Cell and Developmental Biology | | 2 | 9 | 12 |
| Plant Biology | | | 4 | 17 |
| Life Support | | | | 0 |
| Planetary Protection | | | | 1 |
| Exobiology | | | | 0 |
| Top Level Countermeasures | | 1 | | 0 |
| Total | 2 17 | 6 | 16 | 41 |
| Critical Questions Which only Require R&A | #2000000000000#000000000000 | a 1 | | |
| Behavior, Performance and Human Factors | | | | 0 |
| Regulatory Physiology | | | 1 | |
| Cardiopulmonary | | | | 0 |
| Environmental Health | | | | 1 |
| Musculoskeletal | | | | 0 |
| Neurosciences | _ | | | 0 |
| Radiation Health | 3 | 15 | 2 | 22 |
| Cell and Developmental Biology | | | 4 | 4 |
| Plant Biology | _ | | | 0 |
| Life Support | | 3 | | 4 |
| Planetary Protection | | | | 0 |
| Exobiology | | 1 | 3 | |
| Total | 3 (| 19 | 10 | 36 |

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TABLE 1

CRITICAL QUESTIONS FROM ALL LIFE SCIENCES DIVISION DISCIPLINE SCIENCE PLANS

CATEGORIES

- Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral 2 manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew 3 health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- Science Specifically enabled by Moon and/or Mars Missions.
- Basic Research Not Directly Applicable to Moon and/or Mars Missions. 5
- Indicates primary category of application.

CRITICALITY

- Consensus that answer is required for Mars mission. (known effect and known problem for mission).* Criticality 1:
- Answers might be required, science basis to evaluate risk is not adequate.* Criticality 2:
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| 1. | Sci | ence Readiness Levels |
|----|-----|--|
| | 1. | Only folklore of practitioners and anecdotal data available |
| | 2 | Basic scientific concept formulated |
| | 3. | Ground models developed, flight validation required |
| | 4. | Flight validation performed |
| | 5. | Countermeasures identified |
| | 6. | Countermeasures tested |
| | 7. | Operational requirements established |
| 2 | Tec | chnology Readiness Levels |
| | 1. | Technology need identified |
| | 2 | Technology and conceptual solution available |
| | 3. | Component and/or breadboard validation in laboratory environment exist |
| | 4. | Flight validation performed |

- 5. Systems/subsystem prototype demonstration in a relevant ground or space environment completed
- System prototype demonstrated in a space environment
- Actual system completed and flight qualified through test and Demonstration
- Actual system "flight proven" through successful mission 8 operations
- 3. Schedule (information required by)
 - Near term < 5 years
 - Mid term 6-10 years
 - Far term > 10 years
- Effort Required
 - Substantial
 - Moderate
 - Low
- 5 Defined Sequence (Clearly defined sequential path for scientific investigation exists)
 - Yes
- No 6. Parallel/Alternative Path (are parallel or alternative pathways appropriate)
 - Yes
- No
- 7. Ground-based
- Ground-based research required
- A Spacelab
 - Spacelab would be used for research
 - EDO Spacelab needed for Extended Duration Orbiter
- Program research
- 9 SSF
 - Space Station Freedom would be used

- Centrifuge
 - SSF Centrifuge Facility would be used
- Free Flyer
 - Free flyer biosatellite Lunar Base
- 12. Lunar base would be used
- 13. Robotic Explores
- Other Requirements
- Robotic explorer would be used
- Requirement for flight resources other then those identified in 8-10
- Flight Validation Required
 - Flight validation required
 - Not required
- **Facilities Sufficient**
 - Current ground facilities (NASA Centers, Universities
 - and provide industry) are sufficient.
- Current ground facilities insufficient
- **Community Sufficient** 17.

18.

- There is a sufficient scientific community already committed or recruitable
- Scientific community is insufficient
- **Attract New Community**
- Activity will attract new scientists
 - Activity will not attract new scientists
- Group with other disciplines (can this activity be grouped with others from different life science disciplines?)
 - No, cannot be grouped
 - Do not know at this time
 - Behavior, Performance and Human Factors
 - Regulatory Physiology 5. Cardiopulmonary
 - 6. Environmental health
 - Musculoskeletal
 - 8 Neuroscience
 - Radiation Health
 - 10 Cell and Developmental Biology
 - Plant Biology
 - 12 Life Support

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Page 1

Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| 0 | Factors/Crew | 1a3 | | 1a4 | 1a6 | 1a8 | 1a9 | Factors/Selection | 161 | 162 |
| ٦ | _ | | govern optimal assignment of responsibilities between space crews and ground teams and among crew and team members? What ground-based organizations are required for effective support of tlight crew performance on a Mars mission? | | | , , | | | ics atric for | ng. |
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| Question | Performance, | najć | l as cre me are forn | oritic Xisio Peri | criti ipro opti n? | What are the optimal communication procedures for coordination among crew members and betw ground and space crews? | How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? | Performance, | Sgic Pe C | What are the protocols for training effective ground teams and space crews in problem solving enhanced communication, crew coordination, and interpersonal dynamics? |
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| 1_ | Behavior, | 9. | opt opt id te ation | What are the involved in de space crews combination? | 6 t 6 E | and and | ses oup fere | Behavior, | What psychologic are exclusary? \ criteria should be a Mars mission? | tea tea ed rsor |
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| 15 | Beh | What are the major human factors principles that | govern optimal assignment of responsibilities between space crews and ground teams and amccrew and team members? What ground-based organizations are required for effective support flight crew performance on a Mars mission? | What are the critical elements and processes involved in decision- making by ground teams and space crews operating autonomously or in combination? | What are the critical characteristics of leaders that effect reciprocity and productivity of crews? What are the optimal crew command structures for Mars mission? | What are the optimal com for coordination among cri ground and space crews? | How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? | Be | What psychological and behavioral characterist are exclusary? What behavioral and psychome criteria should be used for selecting candidates a Mars mission? | Wh. groi enh inte |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| C1 C2 C3 C4 C5 Critical Question Quest# C r1 2 | 7 5 | What are the requirements for adequate quality of 1c1 2 3 1 life as they relate to food, clothing, hygiene, vibroacoustics, lighting, and other personal needs (privacy, recreation) in spacecraft and habitats? What are the optimal designs for living/working areas in spacecraft/habitats to maximize morale and performance? | Behavior, Performance, Space Human Factors/Human-Machine | What are the factors involved in integrating 1d1 1 1 1 automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and countermeasures for particular missions? | What factors should be considered (e.g. maintainability, reliability, operator discretion) when allocating functions between humans and machines? | What are the requirements for formatting, distributing, managing, accessing, updating, and presentation of information for optimal individual and crew performance? What are the requirements for crew input to the data management system? | What are the human factors issues in |

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| * * 2 | | | | | Mad 4 | What are the behavioral correlates or pnysiological inchance induced by the space environment? | <u></u> | <u> </u> | | 1 | | <u></u> - | | | | _, | | | | | | | | | | | |
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| | | | | | | and motor skills change in space? What is the time | | | | _ | | | | - | | | | | | | | | | _ | | į | |
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| | | | | | Whi for 1 | What procedures are needed for analyzing missions of for their demands on human performance (e.g. task analytical techniques and models)? | <u> </u> | N | <u>E</u> | <u>e</u> | 2 | ~ | | <u>× </u> | <u>~</u> | | | < | | | | <u> </u> | | · | | | |
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Critical Questions From All Life Sciences Division Discipline Science Plans

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Critical Questions From All Life Sciences Division Discipline Science Plans

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| (1) | 2 . 3 | 4 | | | What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological changes incurred in space affect task performance? | 1115 | 2 | <u>ო</u> | 8 | - | × | × | × | × | <u>`</u> | × | | _ | | | <u> </u> | ń | : \ | , | | |
| + | 十 | +- | + | \top | erformance, Space Human | Factors/Stress | s . | | | | | | | | Ì | } | - | - | | f | \dashv | | | | | |
| +: | 2 3 | + | | | e effects of stress on crew and ground mance and what method of detection ntion strategies (e.g. selection, ew support) would prove effective? | 191 | 8 | 9 | - | - | e | × _ | × | | | × | | - | | - | 4 | _ | | | | |
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| | | | 4 | | re the factors that shape individual and team ion and the ability to cope effectively with mental stress? | 193 2 | N | - | ~ | - | ო | × | × | | | × | | | N | - | <u>-</u> | 4 | | | | |
| | ٠, | | | | ocols for sustaining crews w member inflight, or loss friend on earth? | 195 3 | 2 | <u>e</u> | 2 | ო | က | × | × | | | × | | - | - | | - | _ | | | | |
| | | | | | REGULATORY PHYSIOLOGY/Circadian Rhythms | hms | Ī | ŀ | } | - | | | - | - | | Į | - | | | | | | | | | |
| | 8 | | 4 | | What are the effects of the space environment on sleep, sleep cycles, or the generation, expression (period, phase, amplitude and/or waveform), and entrainment of metabolic, endocrine, reproductive, and/or behavioral circadian rhythms? Of these effects, which result from altered gravity and which result from other environmental factors? | 2a1 | е | 7 | <u>N</u> | α | - | × | × | × | | × | | <u> </u> | • | | - | ພຸ 4. | ် ဂ် | _ | | |

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| | | What are the effects of intermittent and variable gravity fields on circadian rhythms, and how does this affect the use of artificial gravity as a countermeasure to microgravity? | ns for s in alth | What are the optimal conditions for synchronizing the circadian rhythms of mission control personnel to the mission schedules? How is performance of mission personnel affected by their various work-rest schedules? | d K? of | is for on | nt? | |
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| | | What are the effects of intermittent and variable gravity fields on circadian rhythms, and how do this affect the use of artificial gravity as a countermeasure to microgravity? | syr nd v t sol | the dian ssio pers | and naco sed the the logic | the the | app the | the hem ht-in nd s |
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| | 2 | What are the effects of intermittent and vagravity fields on circadian rhythms, and how this affect the use of artificial gravity as a countermeasure to microgravity? | What are the optimal environmental conditions ensuring synchronization of circadian rhythms i space, and what are the most appropriate work-rest schedules for ensuring optimal health and performance? | What are the op the circadian rhy to the mission so mission personn rest schedules? | What are the effects of exercise on circadian rhythms and sleep? What pharmacological and nonpharmacological (e.g. light, exercise) agents can be used to reset the human biological clock? What are the effects of routine administration of pharmacological agents in space on circadian rhythms and sleep? | What are the appropriate ground-based analogs studying the effects of extreme environments or human circadian rhythms? | What are appropriate research models for simulating the effects of the space environment? | What are the effects of non-gravity-related physical-chemical and psychological space-flight-induced stressors on circadian rhythms and sleep? |
| | C2 C3 C4 C5 Critical | | | What are the optimal conditions for synchronizing the circadian rhythms of mission control person to the mission schedules? How is performance mission personnel affected by their various worest schedules? | - CEO> at | <u>> 0 E</u> | ≥ 'ऊ | ≽ढ∺ |
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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Table 1

Critical Questions From All Life Sciences Division Discipline Science Plans

| 7 | 2 | 2 | 7 | ۲ | 2010 C 100 101 D 20 100 CO | | ***** | 113 | ٥ | 6 | | 2 | 1, | 7 | ٩ | 15 | 1 | 12 | 131 | 141 | 5 1 | 61 | 1 | 8 | Group | 3 | other | Ois Si |
|---|---|----------|---|--------------|--|---|-------|--------------|---------------------------------------|---|---|---|----------|------------|----------|----------|---|----|-----|-----|----------------|--------------|--------------|----------|----------|-------|-------|-----------|
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| | | | 4 | ٠ | What are the long-term effects of the space environment on the interaction between the circadian system and ultradian and infradian rhythms, especially reproductive systems? | | 2a10 | 4 | · · · · · · · · · · · · · · · · · · · | | | | | × | × | × | | × | | 8 | - | <u>-</u> | - | | | | | |
| | , | ო | 4 | | What roles do age and gender play? Is there a response of the circadian system to the space environment? | | 2a11 | е 8 | ო | ო | 7 | | <u>e</u> | <u>×</u> × | × | | | × | | | | | - | 4, | ú, | 7 | | |
| | 5 | ო | 4 | | What are the effects of cephalad fluid shifts on circadian rhythms? | | 2a12 | 4 E | <u>ო</u> | 7 | 2 | - | 6 | × | × | × | | × | | | | | - | 4. | 2 | | i | İ |
| | | L | | _ | REGULATORY PHYS | PHYSIOLOGY/Endocrinology | | | | | | | | | • | | | | | | } | | ŀ | \dashv | | | | |
| | 2 | е | 4 | | What are the effects of space-induced endocrin changes on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, energy metabolism)? | and | 2b1 | - | <u>ν</u> | N | N | 8 | m | × | × | × | × | × | | 1 | _ | <u>-</u> | - | <u> </u> | 4, | 5, 6, | ^ | |
| - | | | 4 | ر | What are the hypothalamic-pituitary-adrenal are opioid system responses to normal space-fligh events (e.g. EVA, countermeasures) as well as reference "standardized" physical, emotional, environmental stimuli? | t to and | 292 | 4 | | | | | | × × | <u>×</u> | | | × | | | | _ | | | | | | |
| | | | 4 | 'n | 5 * What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | | 263 | 4 | | | | | | × | × | × | | × | | | _ | | | | | | | |
| | 8 | | 4 | ro * | | tction, the parrier, and the les? | 2b4 | 4 | | | | | | × | × | | | | | | - | - | - | 4, | ∞ | | | |
| | | | 4 | ις. • | | ¥ith C | 265 | 4 | | | - | | | × | × | <u>×</u> | | × | | | - | | | | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions From All Life Sciences Division Discipline Science Plans

| 2 | | ĽĊ | C1 C2 C3 C4 C5 Critical Operation | | C | . L | يا : | Ļ | Ŀ | | : | . r | | | | L | L | L | L | | | Ī | - [| | İ | ı | ſ |
|---------------------------|-----------------------------|---------------------------|--|--------|---|-----|------|----------|---|-----|----------|------------|----------|----------|-----|-------------|----|----|--------------|--------------|--------------|--------------|-------|-------|---------|---|------|
| | 200 | 2000 | | Quest* | ပ | 딤 | 2 | <u> </u> | 4 | 5 | 9 | 7 [| 8 | | 101 | 11 12 | 13 | 14 | 15 | 16 | 17 | 18 | Group | /w dr | / other | | Disc |
| REGUL | REGUI | REGUL | REGULATORY PHYSIOLOGY/Hematology | | | | | | | | | | | | | | ļ | | | | | | | | | | |
| Does the cell ma | Does the | Does the cell ma | Does the well documented decrease in red blood cell mass termed "anemia of space flight" | 2c1 | ဗ | 4 | 8 | 2 | 3 | 2 | 6 | × | × | × | × | | | | _ | | - | - | 4, | | | | |
| repres | repres | repres adapti | represent a normal microgravity-associated adaptive process (self-limiting) or a transient | | | | | | | | | | | | | | | | | | | | | | | | |
| respor about (stres | respor about (stres | respor about (stres | response (self. correcting) to changes brought about by various space-flight-related stimuli (stressors)? | | | | | | | | | | | | | | | | | | - | | | | | | |
| 5 • What a change | 5 • What chang flight | What chang flight | 5 • What are the time courses and magnitudes of changes in the erythropoietic system during space flight? | 202 | 4 | | | | | | | <u>×</u> | × | × | | × | | | - | - | - | - | | | | | |
| What mass Shoul | What mass Shoul | What mass Shoul | What is the most effective way to restore red cell mass during simulated and actual microgravity? | 2c3 | ო | 7 | α | 6 | က | N N | <u>е</u> | _ <u>×</u> | <u>×</u> | <u>×</u> | | | | | - | *** | - | N | 4, 5, | . 7. | ω | | |
| flight? they o | flight? they o | flight? they c | flight? Are these acute or chronic changes and are they of sufficient magnitude or duration to pose an unacceptable medical risk and warrant the | | | | | | | | | | | · | | | | | | | | | | | | | |
| develo | develo | develo therap | development of countermeasures (prophylactic or therapeutic)? Formulate mathematical and | | | | | | | | | | | | | | | _ | · | | | _ | | | | | |
| compu | compi | transi | computer models of tissue adaptation and cellular transient response to altered load histories? | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 • What hemat | 5 * What hemat levels | What hemat tevels | 5 • What is the relationship between attered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | 205 | 4 | | | | | | _× | × | <u>×</u> | _× | × | | | | - | - | - | _ | | | | | |
| | | | • | | | • | • | • | • | | • | • | | | | | | • | • | • | • | • | | | | | • |

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Critical Questions From All Life Sciences Division Discipline Science Plans

| | | | | | A 1 8 9 1 C | 0 | 1 | F | - | 5 | 9 | 4 | 8 | 6 | 10 11 | 1 12 | 13 | 14 | 15 | 16 | 17 | 18 Gro | Group w/ other | / othe | er Disc |
|---------------------------------------|---------------|---------------------|-------------------|---|-------------|---|---|---|--------|---|---|---|------------|---------------|-------|--------|----------|----|----|----|----|--------|----------------|--------|---------|
| C1 C2 C3 C4 C5 Critical | 4 C5 Critical | 5 Critical | Critical | Question | #16 B B B | | T | Т | T | 4 | 4 | | Т | + | +, | ╀ | | | ١, | Ţ | + | | | | |
| 4 5 * What are mechanis | 5 * | • What are mechanis | What are mechanis | 5 * What are the major factors and associated mechanisms that contribute to the "anemia of | 2c6 | 4 | | | | | | | × | <u>~</u> × | × | | | | - | | | | | | |
| space – Wh | space — Wh | space — Wh | space – Wh | space flight"? — What controls the atterations in red cell | | | | | | | | | | | | | | | | | | | | | |
| produc | produc | produc | produc | production or survival? | | | | | | | | | | | | | | | | | | | | | |
| impair | impair | impair | impair | impairment of the red blood cell proliferation | | | | | | | | | | | | | | | | | | | | | |
| proces | proces | proces | proces | process or to differential margination, | | | | | | | | | | | | | | | | | | | | | |
| reticu | other | other | other | reticuloendothelial sequestration, cen deaut, or other mechanisms? | | | | | | | | | | | | | | | | , | | | | | |
| 4 5 * Is the | | s the | ls th | 5 * Is the "anemia of spaceflight" related to a direct | 2c7 | 4 | | | | | | | × | × | × | | | | | | | | | | |
| | | effec | effec | effect of microgravity or other | | | | | _ | | | | | | | | | | | | | | | | |
| struc | spac | Struc | struc | structure, function, or cellular interaction? | | | | | | | | | | | | | | | , | | | | | | |
| 5 * Are | 5 * Are | 5 + Are | Are | 5 * Are periods of recovery from "anemia of space | 2c8 | 4 | | | | | | × | <u>×</u> _ | × | | | | | | | | | | | |
| fligh | fligh | fligh | fligh | flight" physiologically analogous to those in | | | | | | | | | | | | | | | | | | | | | |
| ans elva | igns elva | ans ele | scale Ple | subjects who donate blood of curefines are ago phiebotomy, and can this recovery be accelerated? | | | | | \neg | | | | _ | | ᅦ | ㅓ | \dashv | 4 | |] | | + | | | |
| BE | BE | BE . | , BE | REGULATORY PHYSIOLOGY/Immunology | | | | | | | ŀ | } | | | ŀ | } | - | - | - | | | _ | | | |
| 4 5 * Do | Т | 2 | ع ا | 5 - Does space flight affect the humoral or | 241 | 4 | | | | | | × | × | × | × | × × | | | _ | _ | - | | | | |
| , | , | ₹ - | 8 | cell-mediated immune functions, nonspecific | | | | | | | | | | | | | | | | | | | | | |
| imi ees | בנים | ביים | ב ב ב | immunity, or immune surveillative capabilities of | | | | | | | | _ | | | | | | | | | | | | | |
| 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 | 를 <u>하</u> | 다 다 | 2 2 3 5 | nacceptable medical risk while on a mission, | | | | | - | | | | | | | _ | | | | | | | | | |
| odn | od n | od n | <u>a</u> | upon return to Earth, or as a consequence of | | | | | | | | | | | | | | | | | | _ | | | |
| rep | rep | repe | ğ. | repeated mission exposure? | _ | | _ | _ | - | - | - | - | - | _ | - | - | • | • | | | | | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

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Critical Questions From All Life Sciences Division Discipline Science Plans

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|--------------------------|--------------|--------|----------------|--------------|---|-------------|--------|---|-----|----------|-----|---|----------|---|----------|---|-------------|---|--------------|-----|----------------|----------|-----|----------------|----------|---------|
| $\overline{\mathcal{Q}}$ | 22 | ဌ | \mathfrak{P} | છ | C1 C2 C3 C4 C5 Critical Question | Quest# C | | 2 | · _ | ₽ | ٥ | 4 | 0 | 7 | 5 | - | | - | 7 | , | : - | | | | | Τ |
| | . 0 | 8 | 4 | | Are there terrestrial (1 g) human, animal and/or computer models that simulate or reproduce the effects of space flight/microgravity with regard to the immune system in space? | 2d6 4 | ო | Ν | - | 2 | ო | × | × | | <u> </u> | | | | 2 | | | <u> </u> | _ | | | |
| | | | 4 | νn | 5 • What are the effects of space flight on the functional capacities of the effector/accessory cells of specific or nonspecific immunity (monocytes, neutrophils, macrophages, lymphocytes, and NK cells)? | 247 | 4 | | | | | × | × | × | | × | | | - | | | <u> </u> | | | | |
| | | | . <u> </u> | ഗ | 5 • Do any of the changes in the immune system predispose crewmembers either during or after flight to infectious diseases, allergies, or delays in recovery from disease or wound healing? | 2d8 | 4 | | | | | × | × | × | | × | | | - | _ | | | | | | |
| | | · E | 4 | | How long do neutrophilia, lymphocytopenia, monocytopenia, eosinopenia, and reduced blastogenic responses persist after flight? | 2d9 | ю И | 4 | N | 7 | - 2 | | × | × | | - | | | | _ | | 4 | | | | |
| | Ν | | 4 | Ŋ | 5 • Are there other in-vitro/biochemical assays that reliably predict or reflect decreases in immune function and if added to the current battery of postflight tests, would give a more complete picture of factors affecting immune function? | 2d10 | 4 | | | | - | × | | | | | | | N | | | | | | ! | |
| | \downarrow | ↓_ | | +- | REGULATORY PHYSIOLOGY/Metabolism and | d Nutrition | ion | | | | - | ŀ | - | | | ŀ | - | - | | | | + | | | | |
| | 0 | ļ | 4 | | Is the basal metabolic rate and metabolic efficiency altered during extended space flight? Are there changes in energy metabolism and storage in space, especially in substrate utilization? | 2e1 | 8 | N | N | - | 2 | | | × | × | | | | - | , | , , | 4 , | | _ | | <u></u> |
| | Ν | | 4 | | What are the effect of changes in cell and nutrient turnover during space flight on nutritional requirements? | 2e2a | 4 | 2 | 7 | - | N | × | <u>×</u> | × | × | | | | - | | | <u> </u> | | | | |

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Table

Critical Questions From All Life Sciences

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| Division | ō | 78 | 203 | 264 | 295 | 206 | 297 | 208 |
| VIQ | C1 C2 C3 C4 C5 Critical Question | What are the optimal noninvasive microanalytical methods and techniques for use during space flight to monitor nutritional status? | What are the mechanisms underlying the negative nitrogen balance and changes in lean body mass incurred during space flight? What are the possible interventions, including dietary afterations in proteins and amino acids? | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space [light? | Do the effects of space flight require added supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? | 5 What are the energy requirements of EVA? What are the effects of deconditioning, EVA, and countermeasures on nutritional requirements and body composition during space flight? | 5 • Are there valid ground models and analogs for the study of the effects of space flight on nutrition? | What is the time course and nature of body composition change due to space flight? Do changes in body composition (age and gender) have an effect on crew health and performance? |
| | 2 | | | • | | | 4 | 4 |
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Critical Questions From All Life Sciences Division Discipline Science Plans

| 10 | 18 18 | N N | ঠ | ম | C1 C2 C3 C4 C5 Critical Question | Quest# C | = | 2 | 3 | 4 | 5 | 9 | 7 | 8 | 9 | 0 | - | 2 13 | 14 | 15 | 16 | 17 | 18 | Group w/ | / X | other | Disc | |
|-----|----------|----------|---|---------|--|-------------|---------------|--------------|----------|----------|---|--------------|---|---|---|---|------------------|------|----|----|--|--------------|--------------|--|------------|-------|------|--------|
| 8 | | | | ÷ . | the optimal presentation, nutritional and rmulation of the diet for maintaining that and performance in space flight? What ehavioral and performance responses of is to particular food constituents during that? Are there changes in dietary | 269 | | | | | | | × | × | × | | × | | | - | ▼ | | - | | | | • | |
| | | | | ۍ* | | 2010 4 | | | | | | | × | × | × | | × | | | | | | | | | | | |
| | 49 | e e | 4 | | Does space flight after gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | 2011 | Ν | - | Ν | N | N | ო | × | × | × | × | × | | | - | <u>-</u> | - | <u></u> | <u>4, </u> | | | | |
| | | | | , c | related and light its? | 2012 | | | | | | | × | × | × | × | × | | | | | | | | | | | |
| ~ | | | | 5 | abolism dified by | 2013 4 | | | | <u> </u> | | | × | × | × | × | <u>×</u> | | | | <u>- </u> | | - | | | | | |
| | | е | | | ire of space flight-induced changes oactive drugs? | 2614 | | <u>ო</u> | Ν | | 8 | - | × | × | × | × | <u>×</u> | | | - | | | | _ | | | | |
| | | е | | | ght-induced effect of | 2015 | 2 | <u>6</u> | 7 | - | 2 | - | × | × | × | × | * | | | | - | | | 6, 4 | | | | |
| i . | | | | | REGULATORY PHYSIOLOGY/Fluid and Elec | Electrolyte | Regulation | la la | u o | - | - | ļ | | | | Ī | - | + | - | - | F | - | Ŀ | | . | | | \top |
| l | | 3 | 4 | | What are the time course and magnitude of fluid shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during return to 1 g after flight? | 2f1 | <u>က</u> က | <u>~</u> | <u>N</u> | 8 | 7 | Ν | × | × | × | × | | × | | | | - | - | 4, | ιn | | | |

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Table

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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| | | | 4 | <u>ب</u> | 5 • How does the regulation of body temperature change during space flight? How do these changes affect the response to thermal load? | 295 | 4 | | | | | | | < : | < > | | | · · | · · · · · | | | | | |
| | | | 4 | 2 | 5 • How are changes in body temperature or its regulation correlated with metabolic rate and | 296 | 4 | | | | | × × | <u>×</u> | × | <u> </u> | | | | | | | | | |
| | 7 | | | -rc | energy expenditure? 5 • How does space flight affect central and/or peripheral thermoregulatory mechanisms? | 2g7 | 4 | | | | | × | × | | <u>*</u> | _ | | | - | | | | | |
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Critical' Questions From All Life Sciences Division Discipline Science Plans

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| | C1 C2 C3 C4 C5 Critical Question | Of the various countermeasures available to combat adverse cardiovascular effects on long-and short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. | What are the specific mechanisms underlying the orthostatic hypotension observed after flight? What are the effective countermeasures for this? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? | What is the relationship between the cardiovascular adjustments to space flight and those occurring in Earth-based models such as bedrest, immersion, and head-down tit? | ight and ? Are by space | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | |
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| C1 C2 C3 C4 C5 Critical Question | countermeasures to adverse | cardiovascular effects of long- duration space flight affected by changes in fluid distribution? | Are there appropriate animal and/or computer models for studying each functional element of cardiovascular adjustments to microgravity? | ayed r e both | in the near-term (hours to days) and long-term (months to years) after flight? | and | What, if any, are the cardiovascular morphological changes associated with acute or long-term | exposure to space flight (e.g., effects of microgravity, radiation, or environmental hazards in the spacecraft)? | both muscle in the leg luring long-term space flight? Indothelial structure and such exposure and what are the | ure of the interplay between and electrophysiological responses to |
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Table 1

Critical Questions From All Life Sciences Division Discipline Science Plans

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| 5 | 8 | ខ | 3 | ৪ | C3 C4 C5 Critical Question | Quest# | L'O | - | 2 3 | 4 | 5 | 9 | 1 | <u> </u> | 6 | 100 | E | 12 | 13 | 14 | 7 | 1 | ᄃ | 4 P | | | |
| | | | 4 | | What are the correlations between the physiological responses demonstrated in the various microgravity study environments (e.g., KC-135, COSMOS, RAHF) that are available? | 3a18 | 4 | 4 | 9 | <u>m</u> | - | 2 | | | | | 1 | | | | 5 | , | | | door | Jeulo | DI SC |
| | | | 4 | | For the well documented changes in calcium metabolism associated with space flight, what are the direct and indirect consequences for electrical, mechanical, and vascular events in the heart? | 3a20 | en e | ن | <u></u> | ტ | - | 0 | _× | _× | _× | _× | | | | | | | | Ν | | | |
| | 8 | | | | What is the relationship between cardiovascular response and exposure to varying gravity levels (force, internal frequency, and time interval)? Is there a threshold? | 3a21 | N | <u>ო</u> ო | | 0 | | <u> </u> | × | | × | × | | × | | | | - | - | 4, | S | | |
| | | | 4 | | What is the nature of microgravity-associated changes in the autoregulatory mechanisms of arterioles, venules, and lymphatics? What role do these changes play in the adaptation to microgravity and return to normal gravity? | 3a24 | 4 | 8 | ო | - | | Ν | | × | × | × | | | | N | | | | | | | |
| | N | г | 4 | | Are there changes in cardiac performance and contractile efficiency during long term exposure to microgravity? | 3a26 | ы 4 | <u>∞</u> | е | ღ | | | × | × | × | × | × | | | | | | | Ŋ | | | |
| | | | 4 | | Does redistribution of blood volume and flow during space flight affect pH, PO2, or PCO2 in tissues of any organs and vice versa? | 3a27 | 4 © | 4 | <u>ල</u> | ო | - | - | | × | × | × | | | | 2 | | | | | | | - |
| | | | | | Are there cellular and subcellular changes in function in the heart? Are there changes in myocardial contractile proteins? Is there a change in excitation-contraction coupling mechanisms induced by space flight? | 3a28 | <u>.</u> | ო | . n | - | е | м | × | × | × | × | | | | N | - | - | | <u> </u> | | | |
| | | 4 | - | - 3 | What are the uses of microgravity for better understanding of cardiovascular function on Earth? | 3a29 4 | | ã Ž | <u>e</u> | <u>£</u> | £ | Ę | × | × | | | | × | | | | | | | | | |
| \dashv | \dashv | \dashv | \dashv | ᅴ | CARDIOPULMONARY/Pulmonary | | ┨ | - | - | | |] | 7 | 1 | 1 | 1 | 1 | - | 4 | _ | _ | 4 | _ | 1 | | | Τ |

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Table 1 Critical Questions From All Life Sciences
Division Discipline Science Plans

| 150 | 18 | T R | 7 | 8 | C2 C3 C4 C5 Critical Question | Quest# C | 1 | 2 | 8 | 4 | 5 6 | 2 9 | 8 | 6 | ٤ | = | 12 | 13 | 14 | 151 | 16 1 | 7 | 18 G | Group w/ other | /% | other | Disc |
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| | 5 | 3 ° E | 5 | 8 | of size | 352 | N | 7 | е | 2 | - | × | × | × | × | | | | | - | _ | _ | 4, | 5, | 9 | | |
| | · · · | • ო | | | Which pulmonary life support procedures should be used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? | 3b3 | N | | 8 | - | - | | × | × | | - 1.,- | × | | | - | - | | 9 | 40 | | | |
| | | | 4 | | Does space flight affect pulmonary aging or disease processes commonly found in adults in a 1-g environment? How is subclinical pulmonary pathology (e.g., incipient bronchospasm, early emphysema) affected by space flight? Do these same questions apply to healing processes in the lung? | 365 | e | N | ග | _ | N | | × × | <u>×</u> | × | | | | | α | - | <u>-</u> | - | α | | | |
| | N | က | | | Is pulmonary function altered in long-duration space flight at rest, exercise, or in a disease state? | 3b6 | ь 4 | <u>ω</u> | ო | ო | _ | - | <u>^</u> | × | × | | | | | - | - | _ | - | S. | | | |
| | N | ဇ | | | Are there appropriate animal and/or computer models for studying each functional element of pulmonary adjustments to microgravity? What is the relationship, if any, between the pulmonary adjustments to space flight and those occurring in Earth-based models such as bedrest, immersion, and head-down tit? | 357 | 4 Θ | 4 | | N | - | - | <u>^</u> | × | × | × | × | | | - | - | - | - | ည | | | |
| | | | | <u> </u> | ENVIRONMENTAL HEALTH/Toxicology | | | | | | | | | | | | | | | | | | | | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

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| 5 | | 8 | 2 | 8 | C2 C3 C4 C5 Critical Question | Quest# | C r | 1 | 2 3 | 3 4 | 2 | 9 | _ | 8 | 6 | 10 | 1-1 | 21 | 31 | 4 | 15 | 6 17 | 118 | B Group w | 10 dec /4 | ي د |
| - | | ო | | | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | 4a1 | 2 | N | 0 | 0 | N | - | | × | × | × | × | | | · - | · - | · - | · - | | | |
| - | | ო | | | How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight conditions? | 4 a2 | 8 | m m | ۳ ا | | <u> </u> | Ψ- | × | × | × | | × | | | - | - | | | | | |
| - | | က | | | What are the potential biomarkers for assessing either exposure or response to chemicals? | 4 a5 | e e | 2 | <u>හ</u> | က | N | - | × | | × | × | <u>×</u> | | | | | | | 4, 8 | | |
| - | 0 | | | | What are the effects of chronic exposure to ultrafine and larger (respirable and nonrespirable) particles on crew health, safety, and performance? | 4a6 | Ν. | <u>გ</u> | <u>ო</u> | Ν | 8 | - | × | × | × | · | <u>×</u> | · | | ▼ | - | - | _ | S | | · · · · · · · · · · · · · · · · · · · |
| - | | | | | What approaches may be used when insufficient data are available to allow prediction of acceptable exposure levels? | 4a7 | 2 | 4 | - | N | C) | | × | | | | | | | N | <u> </u> | _ | 7 | | | |
| \Box | _ | | \exists | \exists | ENVIRONMENTAL HEALTH/Microbiology | | 1 | - | - | - |] |] | 7 | 1 | 1 | \dashv | \dashv | 4 | 4 | _ | ╛ | | | | | |
| - | •• | е | | | What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? | 4b1 | 1 5 | 6 | 2 | 2 | _ | _ | × | × | × | <u> </u> | × | | | <u>-</u> | | - | - | 10 | | |
| . | | | 4 | <u> </u> | What is the effect of space flight on all microorganisms? | 462 | 2 1 | - 7 | ო | က | N | - | × | × | _ <u>×</u> _ | <u>×</u> | × | | | | | _ | | 10 | | |
| | ~ | . . | 4 | <u> </u> | What is the effect of long-duration space flights on the human immune system? (Reg. Physiol see p. 6) | 4b3 2 | <u></u> | ტ_ | ო | 7 | N | - | × | × | | | × | | | | - | - | - | 4 | | |

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Table 1

Critical Questions From All Life Sciences Division Discipline Science Plans

| 5 | _ | ဗ | 2 | ટ | C2 C3 C4 C5 Critical Question | Quest# C | 냕 | 2 | 3 | 4 | 5 6 | 100 | 8 | 6 | 100 | Ξ | 12 | 13 1 | 14 | 151 | 161 | 7 | 80 | Group w/ other | r Disc |
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| | | | | | ENVIRONMENTAL HEALTH | | | | | | | | | | | | | · | ļ | 1 | | ŀ | | | |
| - | | е | 4 | | What, if any, are the interactions between the effects of microgravity on crewmembers and the effects of off-baseline levels of atmospheric parameters, including gas composition, pressure, and temperature? | 4c1 | 2 | ო | N | N | 2 | × | ~ | × | | | × | | | - | | _ | σ | | |
| | 0 | · e | | | What procedures and approaches prevent decompression sickness or minimize crew risk? | 4c2 | 6 | ო | | 2 | 2 | <u>×</u> | | × | | | × | | | _ | <u>`</u> | | <u> </u> | | ···· |
| _ | 8 | 3 | | | Treatment of medical problems of spacecraft inner temperature, and adverse effects of the gaseous environment? | 4c3 | <u> </u> | ო | _ | 0 | 7 | <u>×</u> | × | × | · | | × | | | - | <u> </u> | - | 9 | | |
| | • | | | | What are the effects of all potential atmospheric components, including contaminants and factors on physical and psychological well-being and crew performance? | 4c5 | 2 | ~ | ო | ო | | × | × | × | | | × | | | - | - | _ | <u>ო</u> _ | | |
| - | 8 | | | | What are the adaptations and deteriorations associated with prolonged exposure to unusual atmospheric environments, including the impact of microgravity, and how can countermeasures be utilized against these deteriorations? | 4 C 8 | 2 | | ო | ო | ▼ | - | <u>×</u> × | × | | × | × | | | - | - | | - | | |
| | | ო | | , | What are the risks for bubble formation and clinical decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? | 4c9 | - | 4 | - | 2 | - | e | × | × | | | × | | | - | - | | - 8 | g, | |
| <u> </u> | | | | Щ | MUSCULOSKELETAL/Organ Physiology | | | | | | | | | j | | | | | | | | | ┪ | | |

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|---------|---|-----|-----|---|--------|----------|------------------|----------|--------------|----------------|----------|---|--------------|----------|---|----|------|----|--------------|----------------|--------------|--------------|--------|----------|-------|------|----|
| | | | 3 [| | Quest# | ပ | _ | 2 | 3 4 | 2 | 9 | 7 | 8 | 6 | 0 | = | 2 13 | 14 | 15 | 16 | 17 | 18 | Grou | Group w/ | other | Disc | - |
| 6 4 | 4 | | | What is the time course and extent of muscle atrophy during either prolonged spaceflight or unloading? | 5a1 | 8 | က | 3 | - | - | က | × | × | × | _ | × | | | - | - | _ | - | 3 . 7. | 80 | | | T* |
| 4 | 4 | | | How is muscle metabolism regulated during normal activity and exercise, after acute and chronic unloaded states, and during recovery from unloading? | 5a2 | N | m | <u>წ</u> | | | က | × | × | <u>×</u> | | × | | | - | | - | - | , 4, | 5, 7 | | | |
| 4 | 4 | | | What are the physiological similarities and differences of ground- based models of muscle atrophy and fiber transformation and weightlessness-induced muscle atrophy and fiber transformation? How valid are ground-based models for studying the characteristics of space-flight-induced muscle changes? | 5a4 | б | ო | 9 | _ | - . | ю | × | × | × | | × | | | N | +- | | - | 3, 7, | æ | 3 | | |
| 6. 4 | | | | Does the atrophy from unloading make muscle, tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | 5a9 | | 8 | 8 | <u>-</u> | - | m | × | _ <u>×</u> | <u>×</u> | | _× | | | | | | | | | | | |
| е | | | | How completely and how well does injured muscle repair in microgravity? | 5a10 | ~ | _ 3 _ | ~ | | - | m | × | _ <u>×</u> _ | <u>×</u> | | × | | | - | | | - | | | | | |
| 4 | | | | What are effects of weight bearing on development? | 5a11 | 4 | 2 | <u>e</u> | | | <u>е</u> | × | <u>×</u> | <u>×</u> | × | × | | | - | - - | | | | | | | |
| | | - 1 | 7 | MUSCULOSKELETAL/Cellular and Molecular | | 1 | 1 | - | - | | | 1 | - | - | 4 | 4 | | 1 | 1 | 1 | 7 | +- | | | | | |
| 4 | | | | What are the molecular signals and mechanisms that are responsible for the control of muscle hypertrophy and atrophy, and what are the specific stimuli that are generated by exercise or disuse to signal increased or decreased protein accumulation in muscle cells? | 561 | 6 | 8 | <u>N</u> | _ | - | 6 | × | × | × | | × | | | 2 | - | - | _ m | . 7. | l & . | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

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| | 2 . | | 4 | | | 8 2 2 | 5b2 | က | m m | 3 | - | - | е | × | × | × | × | | × | | | 2 | - | <u> </u> | - | 3, 7, | œ | | |
| | 2 | | 4 | | | What are the effects of altered levels of hormones and their receptors in regulating the physiology of unloaded muscle? | 5b3 | α | m m | 2 | - | | ღ | × | × | × | × | | × | | | - | - | - | 1- | ,4 4 | 5, 7 | ω. | |
| | . 2 | | 4 | | | What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and function of muscle, as investigated by both | 5b4 | α | ო | 2 | | T | ო | × | × | × | × | | × | | | رم د | - | _ | | 3, 7, | œ | | |
| | | | | | | ground-based and flight experiments? How can this information be used to integrate neuromuscular and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | | | | | <u></u> | | | | <u></u> , | | | | | | | | | | | | | | |
| | · N | | 4 | | | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in response to unloading? | 565 | 4 | e e | 0 | 2 | _ | ო | × | × | × | × | × | × | | | - | - | - | - | , 8 | | | |
| | | - | 4 | | | What are the effects of unloading on the muscular intracellular and extracellular matrix? | 5b6 | 7 | ო | ю С | 2 | | က | <u>×</u> | × | × | × | | × | | | _ | _ | - | - | _ | | | |
| | 5 | | 4 | | | What is the molecular basis for the effects of unloading on the susceptibility of muscle to injury or damage upon resuming normal weight-bearing states? | 567 | ო | N | 2 | 2 | - | ო | × | × | × | × | | × | | | 2 | | - | | 3, 7, | ω | | |
| | | <u> </u> | | | | MUSCULOSKELETAL/Organ Physiology | | 1 | | | 1 | | | | - 1 | 1 | | 1 | | | | | | | | ļ | Ì | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| 1 | ő | What are the rate, extent, and time course of and connective tissue loss for different areas the body during exposure to microgravity or simulated microgravity? How is the time con of regional tissue loss correlated with change the tissue stress and strain histories at the site? To changes in regional microcirculation other regional and systemic factors? | Which endocrine and nutritional processes are required for maintenance of bone and connective tissue? How do these processes interact with mechanical loading? Are these processes affected by space-flight? | What are specific countermeasures that impact effectively upon bone and connective tissue structure and function? | What potential risks does bone loss present to development of bone fractures, hypercalcem metastatic calcification, and renal stone formation? | What are the similarities and differences of ground-based models and spaceflight-induced both and connective tissue loss with respect to biomechanical, histomorphometric, biochemical, and hormonal changes? | Is bone loss reversible in terms of mass, ultra- and micro-structural organization, and microstructure? To what extent do irreversible architectural adaptations affect structural integrity? |
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| | 5 | What are the rate, extent, and time course of bon and connective tissue loss for different areas of the body during exposure to microgravity or simulated microgravity? How is the time course of regional tissue loss correlated with changes in the tissue stress and strain histories at the same site? To changes in regional microcirculation? To other regional and systemic factors? | ¥ per de de de de de de de de de de de de de | st ef X | <u>≯#</u> €₽ | ಹಪ್ಹಡ≷ | 2. ਲ ਤ ਲ ≿ |
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| | C3 C4 C5 Critical Question Quest# C | What are histomorphological and architectural 5c7 changes that occur in bone and connective tissue because of space-flight? | How does mechanical stress and changes in stress 5c8 contribute to bone and connective tissue formation? Are stress and/or changes in stress required for continued structural integrity? | What are the critical characteristics or components of normal daily tissue stress and strain histories that regulate bone and connective tissue development, maintenance, and adaptation? How are these characteristics affected by microgravity? | How are regional changes in bone and connective 5c10 tissue related to regional changes in muscle tissue? | How are neuromuscular activation patterns and 5c11 musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to 1-9? | 5c12 4 | and Mol | 4 What are the patterns of in-vivo mechanical 5d1 2 loading (e.g., tissue strain, stress, strain rate, stress rate)in normal and low-g environments? | What are the bone and connective tissue markers 5d3 2 of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used to investigate and predict regional changes in bone metabolism? |
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Critical Questions From All Life Sciences Division Discipline Science Plans

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Table 1

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Critical Questions From All Life Sciences Division Discipline Science Plans

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| | ΙĚ | NEUROSCIENCES/Central | Are there changes in the processing of signals from the semicircular canals or otolith organs th occur with adaptation? Do these changes take place within the vestibular nuclei, cerebellar structures or other related brainstem and cortics structures? What is the time course of such changes and do they correlate with space motion sickness? | What are the circuitry and signals in the vestib nuclei and brainstem that generate a gravito-inertial frame of reference? What are roles of the different regions of the cerebellum | What is the role of thalamo-cortical systems in generating a gravito- inertial frame of referen | What are the neural (morphophysiological) and neuroendocrine bases for motion sickness? What changes in neurotransmitters, neuroendocrine, or neurohumoral release can be correlated with spacmotion sickness? | What neuronal models can be used to understand central processing and adaptation in attered gravitational states? | At what sites do signals from the different receptors involved in gaze, body orientation, posture and motion converge? What are the characteristics of this convergence? | What is the distribution of receptors for anti-motion sickness drugs in central vestibular pathways? |
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| | Cr1 | ω | 4 E | | 3 | <u>ო</u> | <u>ო</u> | 8 | 7 | _0 |
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| | Quest# | 6a7 | 6a8 | | 6b1a | 6 b1b | 6b2 | 6 | 4 | rΩ |
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| | | n neural sleep, an | al system | , | altered oordinati | iensiona d of cent for ogravity? | on of ation of and afte | for moto daptation | and out d endocri ss? | control f adaptat f gravity' |
| | | es in neural as sleep, and | visual system | , | in altered e ad coordinati d | dimensional and of cent ount for microgravity? | ination of leneration of ing, and afte | rres for moto er adaptation | logy, and out c and endocri ckness? | otor control ge of adaptat es of gravity' |
| | | hanges in neural such as sleep, an | the visual system | , | range in attered re the e-head coordinati , and | three-dimensional VOR and of central account for in microgravity? | cordination of for generation of during, and afte | neasures for moto 3 after adaptation | nysiology, and out nomic and endocri n sickness? | fy motor control range of adaptat states of gravity' |
| | | to changes in neural ms, such as sleep, an | ed in the visual system? | tor | on change in attered tat are the d eye-head coordinati bular, and | iate three-dimensionalinear VOR and of centimear Will account for tents in microgravity? | nd coordination of zed for generation of efore, during, and afte | ntermeasures for motons 1-g after adaptation | y, physiology, and out autonomic and endocri notion sickness? | modify motor control amic range of adaptat ared states of gravity' |
| | _ | lead to changes in neural hythms, such as sleep, an | oduced in the visual system avity? | Motor | ization change in altered What are the e and eye-head coordinati vestibular, and | propriate three-dimensional and linear VOR and of central will account for exements in microgravity? | uts and coordination of ganized for generation of on before, during, and afte | countermeasures for moto I-g or 1-g after adaptation | cology, physiology, and out the autonomic and endocri of motion sickness? | ses modify motor control dynamic range of adaptat attered states of gravity' |
| | stion | wity lead to changes in neural cal rhythms, such as sleep, an | e produced in the visual system f gravity? | DES/Motor | stabilization change in attered ss? What are the gaze and eye-head coordination, vestibular, and nputs? | t appropriate three-dimensional lar and linear VOR and of censing that will account for movements in microgravity? | inputs and coordination of se organized for generation of notion before, during, and afte | imal countermeasures for moto artial-g or 1-g after adaptation | rmacology, physiology, and out itrol the autonomic and endocri istic of motion sickness? | ocesses modify motor control s the dynamic range of adaptates in altered states of gravity' |
| | Question | f gravity lead to changes in neural ological rhythms, such as sleep, and? | es are produced in the visual systemes of gravity? | IENCES/Motor | aze stabilization change in attered states? What are the so gaze and eye-head coordinativisual, vestibular, and ny inputs? | most appropriate three-dimensional angular and linear VOR and of centocessing that will account for the movements in microgravity? | nsory inputs and coordination of comes organized for generation of locomotion before, during, and after | optimal countermeasures for moto to partial-g or 1-g after adaptation | pharmacology, physiology, and out t control the autonomic and endocrateristic of motion sickness? | e processes modify motor control hat is the dynamic range of adaptat conses in altered states of gravity' |
| | Question | tered gravity lead to changes in neural of biological rhythms, such as sleep, an ature? | anges are produced in the visual system states of gravity? | SCIENCES/Motor | es gaze stabilization change in attered onal states? What are the ristics of gaze and eye-head coordination visual, vestibular, and ensory inputs? | the most appropriate three-dimensional the angular and linear VOR and of central processing that will account for it in eye movements in microgravity? | s sensory inputs and coordination of outcomes organized for generation of and locomotion before, during, and after | the optimal countermeasures for mote tion to partial-g or 1-g after adaptation avity? | the pharmacology, physiology, and our that control the autonomic and endocritharacteristic of motion sickness? | aptive processes modify motor control What is the dynamic range of adaptat responses in altered states of gravity' |
| | İ | ss altered gravity lead to changes in neural trol of biological rhythms, such as sleep, an iperature? | at changes are produced in the visual system red states of gravity? | UROSCIENCES/Motor | v does gaze stabilization change in attered ritational states? What are the racteristics of gaze and eye-head coordinativarying visual, vestibular, and atosensory inputs? | at is the most appropriate three-dimensional lel of the angular and linear VOR and of centibular processing that will account for ations in eye movements in microgravity? | it are sensory inputs and coordination of cular outcomes organized for generation of ure and locomotion before, during, and afte it? | it are the optimal countermeasures for moto aptation to partial-g or 1-g after adaptation ogravity? | t are the pharmacology, physiology, and oul ways that control the autonomic and endocruts characteristic of motion sickness? | t adaptive processes modify motor control vms? What is the dynamic range of adaptat ofor responses in altered states of gravity' |
| | İ | Does altered gravity lead to changes in neural control of biological rhythms, such as sleep, and temperature? | d in the visual system | NEUROSCIENCES/Motor | How does gaze stabilization change in attered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What is the most appropriate three-dimensional model of the angular and linear VOR and of central vestibular processing that will account for alterations in eye movements in microgravity? | What are sensory inputs and coordination of muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | What are the optimal countermeasures for motor readaptation to partial-g or 1-g after adaptation to microgravity? | What are the pharmacology, physiology, and output pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | What adaptive processes modify motor control systems? What is the dynamic range of adaptat of motor responses in altered states of gravity' |
| | İ | | What changes are produced in the visual system altered states of gravity? | NEUROSCIENCES/Motor | How does gaze stabilization change in attered gravitational states? What are the characteristics of gaze and eye-head coordinati with varying visual, vestibular, and somatosensory inputs? | What is the most appropriate three-dimensiona model of the angular and linear VOR and of centerstibular processing that will account for alterations in eye movements in microgravity? | What are sensory inputs and coordination of muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | What are the optimal countermeasures for moto readaptation to partial-g or 1-g after adaptation microgravity? | What are the pharmacology, physiology, and our pathways that control the autonomic and endocrioutputs characteristic of motion sickness? | What adaptive processes modify motor control systems? What is the dynamic range of adaptation of motor responses in altered states of gravity? |
| | İ | 4 | What changes are produced in the visual system altered states of gravity? | NEUROSCIENCES/Motor | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordinati with varying visual, vestibular, and somatosensory inputs? | What is the most appropriate three-dimensiona model of the angular and linear VOR and of centerational processing that will account for alterations in eye movements in microgravity? | What are sensory inputs and coordination of muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | What are the optimal countermeasures for moto readaptation to partial-g or 1-g after adaptation microgravity? | What are the pharmacology, physiology, and our pathways that control the autonomic and endocroutputs characteristic of motion sickness? | What adaptive processes modify motor control systems? What is the dynamic range of adaptat of motor responses in altered states of gravity' |
| | İ | | What changes are produced in the visual system altered states of gravity? | NEUROSCIENCES/Motor | ა დ 4 | 4 | | What are the optimal countermeasures for moto readaptation to partial-g or 1-g after adaptation microgravity? | က | 4 |
| | C1 C2 C3 C4 C5 Critical Question | 4 | 4 • What changes are produced in the visual system altered states of gravity? | NEUROSCIENCES/Motor | 4 4 | 4 | 4 | е | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions From All Life Sciences Division Discipline Science Plans

| C2 C3 C4 C5 Critical Question | 1 | 1 | 1 | | Quest# | 2 | 1 | F. | 4 | 12 | 9 | 1 | <u>_</u> | 6 | 100 | E | 12 | 13 | 14 | 151 | 161 | 11/1 | 8 | Group | 3 | other | Disc |
|--|--|--|--|------|--------|-------------|----------|----------|----------|--------------|---|---|----------|---|-----|---|----|----|----|--------------|--------------|----------|----------------|----------|----|-------|------|
| hange in otolithic and proprioceptive in requiating calcium | hange in otolithic and proprioceptive in requiating calcium | hange in otolithic and proprioceptive in requiating calcium | hange in otolithic and proprioceptive in requiating calcium | 999 | | 4 | | | | | ļ | × | × | × | × | × | × | | | †= | += | +=- | 4 | | | | |
| or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | | | | | | | | | | | | | | | | | | | | | | | | |
| What models of sensory-motor transformation can 6b7 be used to predict motor behavior best in altered gravitational states? | What models of sensory-motor transformation can be used to predict motor behavior best in altered gravitational states? | What models of sensory-motor transformation can be used to predict motor behavior best in altered gravitational states? | ς | 6b7 | | 4 | 2 | | ო | - | 8 | × | × | × | × | × | × | | | _ | | | <u>က်</u> _ | α, α, | 10 | | |
| 4 5 * How do neural mechanisms regulate homeostatic 6b8 processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | 5 * How do neural mechanisms regulate homeostatic processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | 5 * How do neural mechanisms regulate homeostatic processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | 3.2 | 668 | | 4 | | | | | | × | × | × | × | × | | | | <u> </u> | | | 4 | τ, r, | 0 | | |
| NEUROSCIENCES/Cognitive/Spatial Orientation | 0 | 0 | 0 | tati | no | | | | | | | | | | | | | | | | | 1 | | | | | |
| 3 4 * What are the psychophysical correlates and neural 6c1 basis for perception of motion? | What are the psychophysical correlates and neural basis for perception of motion? | What are the psychophysical correlates and neural basis for perception of motion? | | 6c1 | | 4 | 3 5 | 2 | ဗ | 1 | 2 | × | × | × | | × | | | | <u>-</u> | - | | | 9, 8 | | | |
| *3 4 What psychophysical correlates can best be used to 6c2a describe spatial orientation? | | | What psychophysical correlates can best be used to 6c2a describe spatial orientation? | 6c2a | | | 4 | - | N | +- | N | × | × | × | | × | × | | | - | _ | | | ε, 8 | | | |
| What are the cortical and subcortical neural 6c2b correlates of egocentric and exocentric orientation? | • What are the cortical and subcortical neural correlates of egocentric and exocentric orientation? | • What are the cortical and subcortical neural correlates of egocentric and exocentric orientation? | wral | 6c2b | _ | 4 | е - | <u>ო</u> | ო | - | N | × | | × | | × | × | | | 8 | - | | | 8, 10 | _ | | |
| 3 4 Does a change in vestibular input lead to changes in 6c3 visual and auditory localization and multisensory spatial orientation? | Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | | | | <u>,</u> | 4 | - | ო | | 8 | × | × | × | | × | × | | | _ | | <u>-</u> | | တ ထ | | | |
| What ground-based paradigms and models are most 6c4 effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional environment? How do these interactions change in altered gravity? | What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional environment? How do these interactions change in altered gravity? | What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional environment? How do these interactions change in altered gravity? | nost Ind Sory | | | ო | <u>е</u> | <u>E</u> | <u> </u> | N | ~ | × | × | × | × | × | × | | | - | - | | | ε | | | |

C1=Finvironmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Table 1 Page 30

Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

| | | CALCELO | ACCION | 5 | 100 | | | Г | Γ | Г | Г | ٢ | ┢ | Г | Г | r | H | - | - | | t | H | ŀ | ŀ | _ | _ | | ١ | | 1 | Г |
|--|--|----------|--|--|--|------------------------|--------|---|---|---------|-------------|-----|------------|----------|----------|----------|---|--|----------|---|----------|-------------|----------|----------------|--------------|--|--------------|------|-------|-----|-------------|
| 6c6 4 3 2 3 2 2 X X X X 1 1 1 1 1 1 7, 8, 3 6d3 4 3 4 2 2 1 2 X X X X X X X X X X X X X X X X | | | | | | | Quest# | 5 | _ | 2 | 9 | 4 | 2 | | | | 3 | 0 | 1.1 | 7 | <u>8</u> | 4 | 2 | 9 | 7 | | aroup | * | other | Dis | ပ |
| 6c6 4 1 1 1 1 1 3 8 1 2 1 2 1 2 1 3 1 2 1 3 1 3 1 4 5 2 3 1 2 1 3 1 2 1 3 | 2 • 4 What process joint and boo | | What process joint and boo | What process joint and boo | What process joint and boo | jo | | 2 | - | က | | | | | i | | V | | | × | | - | <u> </u> | _ | _ | | | 6 | | | 1 |
| so of 6d1 4 4 5 2 3 1 2 X X X X X X 2 1 1 1 10, 8 filton 6d3 4 3 4 2 2 1 2 X X X X X X X X X X X X X X X X | 5 • What percep produced by sickness? | • | • | • | What percep produced by sickness? | | | 4 | | | | | | | | | ~ | | × | | | | | | | | | | | - | |
| 195 of 6d1 4 4 5 2 3 1 2 X X X X X X X X 1 1 1 10, 8 and a single of the state of t | NEUROSC | NEUROSC | NEUROSC | NEUROSC | NEUROSC | | | 1 | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | ┪ | ╁╴ | | | | | T |
| from 6d3 4 3 4 2 2 1 2 X X X X X X X 1 1 1 1 1 1 1 1 1 | 4 What are to the otolith of developmen | • | • | What are the otolith of development | What are the the otolith of development | s of | | | | | | | | | | | | | | × | - | - 24 | - | - | - | +- | | | | | T - |
| Ge2 2 3 3 1 2 1 1 X X X X X X X 1 1 1 1 7, 8, 10 gravity Ta2 3 5 1 1 1 NR Ge2 2 3 3 5 1 1 1 NR Ta2 3 5 1 1 1 NR Ta2 3 3 5 1 1 1 NR Ta2 1 1 1 1 1 NR | 3 4 * What are the b mechanisms of and the physiol transmission? | • | • | What are the mechanism and the phytransmission transmission transmission to the mechanism of the mechanism o | What are the mechanism and the phytransmissi | sduction | | | | | | | | | | | | | | ~ | | N | | | | - α | | | | | |
| gravity Ge2 2 3 3 1 2 1 1 X X X X X X 1 1 1 1 4, 5, 7, and a first second of the secon | Will the de vestibular, systems a result in p | | Will the de vestibular, systems a result in p | Will the de vestibular, systems a result in p | Will the de vestibular, systems a result in p | | | | | | | | | | | | | | | ~ | | | | _ | | | | 9 | | | |
| ACR in 7a1 1 3 5 1 2 1 NR X 2 2 1 1 NR 7a2 3 3 5 1 1 1 NR X 2 1 1 1 NR | 4 If an on-bc counterme maintenan cause repe | | If an on-bc counterme maintenan cause repe | If an on-bc counterme maintenan cause repe | If an on-bc counterme maintenan cause repe | | | | | ო | - | · · | | <u> </u> | ~ | <u>×</u> | · | ~ | | | | | | | | 4 | | 7, 8 | | | |
| 3 S T T T T T T T T T T T T T T T T T T | RADIATION | RADIATIC | RADIATIC | RADIATIC | RADIATIC | HEALTH/Space Radiation | onment | Ħ | Ħ | 1 | | | ┨ | 1 | 1 | ł | 1 | 1 | ╢ | 1 | ┨ | 1 | 1 | 1 | ┨ | #- | | | | | 11 |
| 7a2 3 3 5 1 1 1 NR | 4 For a give interplanet energy, LE | | For a give interplanet energy, LE | For a give interplanet energy, LE | For a giver interplanet energy, LE | . <u>c</u> | | | | 2 | - | 2 | | as - | <u> </u> | | | | <u> </u> | | × | | | - | 2 | - | | | | | |
| | 4 5 What is the radiation? | ıc | | | What is the radiation? | | | | | <u></u> | | | _ <u>z</u> | Œ, | | | | | | | <u>×</u> | | | - - | - 8 | | | | | | |

CI=Environmental Health C2=Countemmeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

| 5 | 22 | 8 | 2 | | C5 Critical Question | Quest# C | 1 | 2 | 3 | 4 | 5 | 9 | 7 | 8 | - | - | = | 213 | 3 17 | 4 15 | 19 | 17 | 18 | Group w/ | other Disc |
|--------------|----|-----|--------------|-----|---|----------|----------|----------|---|-------------|----------|----------|-----------|---|--------------|---|----------|-----|----------|------|--------------|--------------|--------------|--------------|------------|
| - | 8 | | 4 rv | S. | What is the trapped radiation flux as a function of time, magnetic field coordinates and geographical coordinates? | 7a3 3 | ဗ | 5 | | - | - | <u>E</u> | | | · | | <u> </u> | | × | α | N | | N | | |
| - | N | e e | 4 rc | 22 | What are the maximum flux, the integrated fluence, and the probability of large Solar_Particle Events (SPE) during any mission? | 7a4 1 | N | <u>E</u> | | | ო | <u>£</u> | × | | | | | | × | 0 | | | N | - | |
| | - | • | 4 | | What are the doses related to heavy ions in deep space? | 7a6 2 | 8 | _ | _ | - | - | <u>£</u> | | | | | | | × | α | N | _ | N | <u>-</u> | |
| - | 7 | | 4 rc | 2 | What are the factors that determine radiation flux of solar flares? | 7a7 2 | 7 | | - | _ | က | <u>£</u> | ········· | | | | | | × | 7 | - | | 7 | - | |
| · | | | | | What will the radiation environment be within the space vehicle and what factors influence the flux, energy, and linear energy transfer spectra of the radiation? | 7a8 1 | N | 4 | - | ~ | ო | က | | × | × | × | × | × | | Ν | | - | - | | |
| . | | | | | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events be improved? | 7a9 1 | | N | 8 | - | 1 | - | × | × | × | × | × | × | | 7 | | | | | |
| | | | | | RADIATION HEALTH/Nuclear Interactions | | | | | | | | | | | | ł | ŀ | ŀ | ŀ | ŀ | - | ļ | | |
| • | 8 | | **/ | 2 | What are the cross sections and yields for nuclear interactions of HZE particles in tissue and shielding materials? | 7b1 3 | ဗ | 7 | - | 7 | _ | 2 | × | | | | | | | 7 | N | | | | |
| - | 7 | | | | What are the angular distributions of nuclear interaction products? | 762 3 | က | N | _ | 8 | _ | <u>£</u> | × | | | | | | | 8 | α | _ | - | _ | |
| - | 8 | | . | | What are the particle multiplicities of nuclear interaction products? | 7b3 2 | ო | 0 | | N | - | £ | × | | , | | | | | 7 | 7 | | _ | <u>-</u> | |
| * | 0 | | / | rs. | How is a radiation field transformed as a function of depth in different materials? | 764 2 | က | 0 | _ | N | - | ፵ | × | | | | | | | 0 | ~ | | | <u>-</u> | |
| - | 2 | | | 2 | What are the optimal ways of calculating the transport of radiation through materials? | 765 3 | <u>e</u> | 4 | | <u></u> | - | <u>£</u> | × | | \dashv | | | | \dashv | 2 | 7 | | - | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

| ŀ | - | ŀ | ŀ | | | | | | | 5 | | | 2 8 1 | | | | | | | | | | | | | | |
|--------------|---|--------|----------|--|--|--------|----------|--------------|---|-----|----------|----------|----------|---|---|---------|---|---------------------------------------|----------------|-----|-----|--------------|--------------|--------------|----------------|----------|-------------|
| C1 C3 | | S 2 | | C5 Critical | Il Question | Quest# | 10 | E | 2 | 3 | 4 | 5 6 | <u> </u> | 8 | 6 | 100 | 1 | 12 | 13 | 4 | 5 | 161 | 17 18 | | Group w/ other | her Disc | ر ا |
| | _ | | | RADIATION | TION HEALTH/Atomic Interactions | | | | | | 1 | 1 | - | - | - | |] | | | 1 | 1 | 4 | \downarrow | - | | | Т |
| - | | | 2 | | What is the precise energy deposition of heavy ions? | 7c1 | 4 | က | 4 | - | 2 | 2 | × | | | <u></u> | | | | 2 | 2 | - | - | - | | | |
| • | | | 2 | | ne yields and energy spectra of | 7c2 | ၉ | က | က | - | 2 | | × | | | | | - | | - 7 | ~ | | | | | | |
| - | | | က | | How can the wealth of knowledge existing for energy deposition in gaseous media be extended to the liquid phase applicable to most living cells? | 7c3 | e | ო | 4 | ~ | <u></u> | <u>E</u> | × | | | | | | | - 0 | | | | - | | | |
| | · | | \$ | | How do diffusion, recombination and other interactions of chemical intermediaries alter the chemical events at the DNA level? | 7c4 | က | ო | 4 | 8 | 2 | <u>E</u> | × | | | | | | | N | | | | - | | | |
| • | | | 2 | | How is physical energy deposition related to biological effect? | 7c5 | က | Ω. | 4 | 2 | <u> </u> | <u>£</u> | × | | | | | ** | - | -2 | N | | | _ | | | |
| | | | _ | RADIATION | TION HEALTH/Molecular Biology | | |] | 1 | 1 | 1 | - | - | - | 1 | | | 1 | - | ┪ | ┨ | 4 | - | | | | Т |
| - | | | <u>ω</u> | | What are the probabilities of GCR to produce radiation damage at specific sites on DNA? | 741 | е е | 6 | 4 | 1 2 | - | <u>£</u> | × | | | | | | | 2 | 7 | <u>-</u> | 2 | - | | | |
| 4 | | | S | | How are processes like oncogene activation and oncogene suppressor inactivation involved in the carcinogenic effects of GCR radiation? | 742 | ო | N N | 4 | 2 | - | £ | × | | | | | | | 7 | N | - | | | | | |
| <u>۲</u> | | | ις | | What mechanisms are involved in modulating radiation damage at the molecular level (repair, errors in repair, gene amplification, etc.)? | 7d3 | ო | <u>ო</u> | 4 | 2 | | <u>£</u> | × | | | | | | - " | 0 | . ~ | | | - | | | |
| <u>.</u> | | | 2 | | How can molecular mechanisms of radiation damage be used to understand effects in whole cells? | 7d4 | <u>е</u> | ა | 4 | 2 | | | × | | | | | · · · · · · · · · · · · · · · · · · · | | ~ | 7 | | _ | | | | |
| - | | | | RADIATION | IION HEALTH/Cellular Biology | | | 1 | 1 | | 1 | - | | | |] | 1 | 1 | 4 | - | 4 | 4 | 4 | _ | | | т- |
| - | | | S. | What is the pro transformation o cancerous cell? | bability of initiating neoplastic cell r other steps leading to a | 7e3 | 3 | 2 | 4 | | | <u>£</u> | × | | | | | | | 2 | 2 | | | - | | | Т. — |

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Critical Questions From All Life Sciences Division Discipline Science Plans Table 1

| | | | | ı | | | | | | | | | : | | | | | | | i | į | | | | | 1 |
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| ប | 8 | ខ | ठ | ડ | C5 Critical Question | Quest# | ر ت | 1 | 3 | 4 | 2 | 6 | 7 | 8 | 9 | 0 1 | 1 1 | 2 1 | 3 1 | 4 1 | 5 1 (| 6 1 | 7 18 | 8 Group w/ | w/ other Disc | Q |
| + | - | | 2 | 2 | How do cellular repair mechanisms modulate damage produced by energetic charged particles? | 764 | 6 | 3 4 | . 5 | 7 | - | £ | × | | | | | | | 2 | 2 | | - | - | | |
| - | | | 2 | ro. | How can the radiation effects on cells in culture be related to radiation effects in "normal" cells and tissues? | 7e5 | 4 | 2 4 | | - | _ | <u>E</u> | × | | | | | | | 0 | N | | | - | | |
| - | | | 2 | 5 | How can cellular mechanisms of radiation damage be used to understand effects in whole organisms? | 992 | . ი | 6 4 | | | <u>. – </u> | <u>£</u> | × | | | | | | | 01 | N | - | | - | | |
| | | | | | RADIATION HEALTH/Animal Models | | | | | | | | | | | | | | | | | | | | | |
| - | | | 2 | 5 | How can animal models be used to extrapolate probabilities of radiation risk to humans in space? | 741 | e | 2 | | - | ၈ | 5 | × | | | × | | | | - | 7 | α | - | - | | · · |
| + | | | <u>v</u> | S. | What is the relative biological effectiveness of different types of radiation for the relevant endpoints such as cancer; cataracts? | 713 | - | 4 | . | | - | 5 | × | ı | • • • | | | | | ~ | N | _ | - | - | | |
| - | | | 2 | ıç. | What is the age dependence of relevant radiation effects in animals (cancer, cataractogenesis, life shortening, etc.)? | 715 | 8 | 2 | - | - | | <u>£</u> | | | | | | | | 0 | 04 | | - | - | | |
| | | | | | RADIATION HEALTH/Humans | | | | | | | | | | | | ł | | 1 | | 1 | 1 | | | | |
| | 2 | | | | What should be the radiation dose limits for manned deep space missions? | 7g1 | - | 2 4 | - | - | - | 5 | × | | | | | | | 7 | ~ | - | - | - | | |
| * | 0 | | ហ | ις. | What is the probability of cancer as a function of dose, dose rate, radiation quality, gender, age at exposure, and time after exposure? What is the effect of GCR at different stages of the carcinogenesis process? | 793 | - | 4 | - | | - | ¥ | × | | | | | | · · · · · · · · · · · · · · · · · · · | 0 | | - | - | - | | |
| - | 8 | | 22 | | What is the probability of cataract formation as a function of the same quantities? | 794 | <u>ო</u> | 2 4 | - | - | _ | 25 | × | | | | | | | 7 | 7 | - | | | | |
| - | <u>N</u> | | <u>ι</u> | ιΩ | What is the probability for genetic and developmental detriment incurred as a consequence of radiation exposure in space? | 795 | <u>ო</u> | S1 4 | | | - | 5 | × | | × | × | | | | | 0 | | ₩- | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| 5 | C2 C3 C4 | ខ | \Im | CS | Critical Question | Quest# | <u>ا</u> د با | - | 2 | 3 4 | -5 | 9 | _ | 8 | 6 | 10 | 1- | 121 | 3 1 | 4 | 5 1 | 6 1 | 1 | 8 | Group w/ other D | Disc |
| - | 8 | د د | | 2 | How are risks associated with acute exposure to space radiation to be managed medically? | 7g6 | | N | 4 | - | က | 5 | × | | × | | | × | | Ι- | - | - | - | o | | |
| _] | 2 - | 3 | | 2 | What pharmacological agents should be developed and tested as prophylactic agents for low LET? | 7g7 | 3 | - | 2 | 2 | ဇ | <u>£</u> | × | × | | | × | × | | | | - | | 2, 8 | | |
| | | | | | PLANT BIOLOGY/Gravity Perception, Tran | Transduction | | and | Re | Response | 186 | | | , | | | | | | | | 1 | | | | |
| | | | | 5. | • What are the mechanisms that underlie gravity perception? | 8la1 | 4 | | | | | | × | × | × | × | | | | - | -2 | - | - | | | <u> </u> |
| | | | | r. | What are the sequential events in gravity transduction and response? | 8la2 | 4 | | | | | | × | × | × | × | | | | | - 2 | | | | | |
| | | | | 'n | * How does a single cell sense gravity? | 8la3 | 4 | | | | | | × | × | × | × | .,, | × | | | ~ | 2 | | 10 | | - |
| - | | | | | What are the thresholds required for gravity to have an effect? | 8la4 | 2 | 8 | <u> </u> | | | <u>E</u> | × | × | × | × | | | | | - 2 | 7 | | | | |
| | | | | 'n | 5 * What changes in the routes of perception, transduction and response occur in microgravity? | 8la5 | 4 | | | | | <u></u> | × | × | × | × | ··· | | | - | - 21 | | | | | |
| 1 | | | I | | What are the differences, if any, between species and their tissues in their perception and responses to gravity? | 81a6 | 0 | - | ~ | - | | Æ | × | × | × | × | | | | | N | 0 | | <u></u> | | |
| | | | | | PLANT BIOLOGY/Reproduction and Develo | evelopment | | | | | | | | | 1 | 1 | | 1 | 1 | | 1 | | ł | | | |
| - | | | | | Can plants successfully reproduce through more than one generation in space? | 8lb1 | 2 | 8 | - | - 1 | - | ¥ | × | × | × | × | | | | - | 2 | -2 | - | 12 | | <u>-</u> |
| - | | | | | Is chromosomal integrity and behavior during cell division affected in microgravity? | 8162 | 8 | 4 | 9 | | _ | Z | × | × | × | × | × | | | - | 71 | 0 | | 10 | | |
| + | | - | | | Is cell, tissue, or organ differentiation affected in microgravity? | 8163 | 2 | <u> </u> | _ | - 2 | | <u> </u> | × | × | × | × | •• | | | | 0 | 7 | | | | |
| - | | | | | What effect does microgravity have on embryogenesis and the ensuing stages of the life cycle of plants from maturity to flowering and senescence? | 81b4 | 8 | _ | | - 8 | - | 2 | × | × | × | × | | | | | <u>8</u> | 0 | | ···· | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

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| <u>.</u> | | | | Are the growth rates of higher plants or single cells affected by microgravity? | | 8156 | ~ | 2 | - | N | N | <u> </u> | × | × | <u>×</u> | | | | | - | 0 | 7 | - | 12 | | |
| | | | 5 | How do plants adapt to microgravity? | | 8lb7 | 4 | | | | | | | × | × | × | | | | - | 2 | 8 | - | 12 | | |
| <u>+</u> | | 4 | | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | | 8168 | 2 | - 2 | - | + | - | <u>É</u> | × | × | × | × | × | × | | - | 8 | 7 | | o l | | |
| | | | | PLANT BIOLOGY/Metabolism | ibolism and Transport | rt | | | | | | | | | } | | | | | [| | | | | | |
| - | | | | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered microgravity? | <u>.</u> ⊆ | 81c1 | 2 | 2 2 | - | - | Y- | £ | × | × | × | | | | | - | 2 | 8 | - | 2 _ | | |
| <u>-</u> | | | | What effect does microgravity have on the synthesis of storage and support polymers? | | 81c2 | 8 | 2 | | - | - | <u>£</u> | × | <u>×</u> × | <u>×</u> | | | | | - | 2 | 8 | - | 12 | | |
| | | | 'n | 5 • What are the effects of the space environment membranes and transport during uptake and secretion? | 8 | 81c3 | 4 | | | | | | × | × | <u>×</u> × | | × | | | - | N | N | - | 10, 12 | | |
| <u>-</u> | | | | Are pathways for plant nutrient absorption altered in microgravity? | | 8lc4 | ۵. | - | - | - | - | 2 | × | <u>~</u> | × | | | | | - | 7 | 2 | | 12 | | |
| - | | | | What are the effects of the space environment long distance transport of water and on transpiration? | onment on | 81c5 | N | - - | | *** | - | <u>£</u> | × | × | × | <u> </u> | | | | - | N | 7 | - | | | - |
| | | | 5 . | 5 • What are the mechanisms by which transport systems are polarized in plants grown in space? | :e3 | 81c6 | 4 | | | | | | × | × | × | × | × | | | - | 2 | 2 | - | | | |
| <u> </u> | | | | Cell, Developmental | Biology(Cell)/I | Neuroscience/Gravity | /Gra | vity | | Sensing | ing | | | | | | | | | | | | | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| C1 C2 C3 C4 C5 Critical Question | If single cells sense changes in gravity directly, what are the intracellular structural/functional mechanisms that are sensitive to gravity perturbation? Is the cytoskeleton organization of cells disturbed by gravity perturbation? How does the cell's cytoskeleton, outer membrane and nuclear envelope/nuclear matrix react to altered pravity as a three-dimensional continues. | fi single cells are too small to detect changes in the gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? | 5 * Do single cells sense alterations in gravity directly, in which cells are part of a gravisensing organ, or indirectly, in which the cells detect indirect consequences of the presence or absence of inertial acceleration? | 6 How do the following modifying factors affect gravity "sensing" at the cell level: cell size; cellular dynamics; changes in cell shape; prokaryotic versus eukaryotic cells; adaptive versus non-adaptive cells; circadian rhythms? |
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| | If multicellular systems are necessary for gravity sensing, how is this effected? What cellular structures and processes that extend across several cells might be involved? What aspects of cell-cell communication are affected? Would the requirements for cellular interaction/assembly increase sensitivity to indirect or environmentally mediated effects (e.g., reduction of cell-cell and cell-surface contact by dispersion of cells in microgravity)? | Biology(Cell)/Neuroscience/Transduction | What are the mechanisms involved in the transduction of the stimulus of altered gravitational force to a cellular response? By what pathways is the perception of altered gravity relayed intracellularly and/or extracellularly? Research indicates that resting/active cells are not measurably affected by changes in gravity. What is responsible for the difference in responsiveness between resting and active cells? |
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Critical Questions From All Life Sciences

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| NO DIE | C3 C4 C5 Critical Question | How are the following cell functions influenced by gravity and/or affected by microgravity: the expression and regulation of genetic information; cell division; cell differentiation; signal transduction, including signal-membrane interactions, membrane-effector interactions, and signal-effector linkage; membrane dynamics; intracellular transport; secretion; alternate pathway regulation; and cell-to-cell communication? The importance of selecting cells and cell lines that can provide interpretable results bearing on precise questions cannot be overemphasized. | factors to their cognate membrane receptors—as an independent variable or a quantifier? What are the contributions of the cytoskeleton, the intracellular pathways of chemically mediated signal transfer, and the nuclear envelope/nuclear matrix to functional response? How will altered gravitational fields and vectors change the information content of the three-dimensional microenvironment of the three-dimensional microenvironment of the change the information content of the three-dimensional microenvironment of the challenges would be wounding of dermal fibroblasts and keratinocytes (or epidermal/dermal wounding in vivo), differentiation of microvessel endothelial cells in vitro (or growth of the microvesculature in vivo, particularly following wounding or tumor implantation), and application of stress to active osteoblasts (or bones in vivo). |
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Table 1 Critical Questions From All Life Sciences Division Discipline Science Plans

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| | | | | <u>^</u> | multicellular systems affected by microgravity? | | | | | | | | | | | | | | | | | | , | | ; | |
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| | | | | | differences between responses that occur as a direct consequence of acute exposure to | | | | | | | | | | | | | | | | | | | | | |
| | | | | | microgravity and responses at a later time, that | | | | | | | | | | | | | | | | _ | | | | | |
| | | | | | may reflect title operation of compensation, mechanisms? | | | | | | | | | | | | | | | | | | Ļ | 1 | Ç | |
| | 2 | e | | | How long can single cells cope with changes in gravitational force without adverse results? Do these effects persist after return to unit gravity? | 811158 | 4 | - | - | - | ი ი | × | × | × | × | × | | | | | | 4 | 6, 9, 7, 9, 10 | · | 2 | |
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| - | | 6 | 4 | | How is the effect of gravity (and microgravity) on ecells influenced by magnetic fields and radiation? | 811c1 | 2 | - | - | _ | გ | <u>×</u> | × | × | | | × × | _ | | 2 | N | <u> </u> | _ | | | |
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| | | How will the reproductive status of premenopausal female crewmembers be managed to minimize the risk of pregnancy, osteoporosis, and hemorrhage from ruptured follicles during ovulation? What is the role of gravity in developmental biology? — Does the developmental ontogeny of animals raised through more than one life cycle under a changed gravity field differ from the 1-g classical pattern? Does this altered pattern reside in the genome, or is it relayed from hormonal and stromal interactions? — Are there critical windows of susceptibility for affected in a gradient? — If gravity-related effects exist, can they be reversed in the short- or long-term? — What will be the result of gravity-induced dys-synchrony (temporal or hormonal) during development? | Which developmental mechanisms have evolved to be dependent on the 1-g gravity field and vector? | t the |
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| | | How will the reproductive status of p female crewmembers be managed to risk of pregnancy, osteoporosis, and from ruptured follicles during ovulatio the role of gravity in developmental — Does the developmental ontogeny raised through more than one life cyclohanged gravity field differ from the pattern? Does this attered pattern respendency or is it relayed from hormon stromal interactions? — Are there critical windows of sus developmental processes, or is develoateded in a gradient? — If gravity-related effects exist, car reversed in the short- or long-term? — What will be the result of gravity-idys-synchrony (temporal or hormonal development?) | ims ty fi | nder |
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| | C1 C2 C3 C4 C5 Critical | ις. | | 5 Which organ systems are dependent on the 1-g gravity field and vector? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Cniticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Table 1 7 Page 41

Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| 3 | 3 | 3 + | <u>;</u> † | made alones have also as a | 81114 | - | - | <u>-</u> | 1 2 | 3 | × | × | | × | × | | | _ | - | <u>-</u> | <u>oʻ</u> | 9 | | | |
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| | | | | cells of protracted, chronic, low dose exposure to | | | | | | | | | | | | | | | | | | | | | - |
| | | _ | | space radiation outside the Van Alleli Delis: Wildi | | | | | | | | | | | | | | | | | | | | | |
| | | | | 6Vents in gametogenesis and early general and box can | | | | | | | | | | | | _ | | | | | _ | | | | _ |
| | | | | maturation are gravity selistive, and how con | | | | | | | | _ | | | _ | | | | _ | _ | _ | | | | |
| _ | | | | these results relate to the promeration and | - | | _ | | _ | | | _ | | _ | | | | | | | _ | | | | |
| | | | | differentiation of other individual cell types: | | | | | _ | | | | | | | | | | | _ | _ | | | | |
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| | | _ | | these results indicate more general mechanisms of | | | | | | _ | _ | | | | | | | | | | | | | | _ |
| | | | | membrane atteration in individual cells? | | _ | | | | | | | | | _ | _ | _ | | | | _ | | | | |
| _ | | | | Which responses are transmitted maternally, | | | | | | _ | | _ | | | | _ | _ | | | | _ | | | | |
| | | | | are intrinsic to the developing embryo? | | _ | _ | | | _ | | | | | | | | | | _ | | | | | _ |
| | | _ | | In which we have a control of the co | | _ | | | | _ | _ | _ | | | | _ | | | | | _ | | | | |
| _ | | | | - What are the results of allered gravity here. | | _ | | | | | _ | | | | _ | | | _ | | | | | | | |
| | | | | the axis polarity and symmetries of the zygote? | | _ | _ | | | _ | - | | | | _ | | | | | | | | | | |
| | | | | Are there gravity effects that can terminate in | | _ | | | | | | _ | | | | _ | _ | | | | - | | | | _ |
| | | | | changes of gene activation? | | _ | | | | _ | _ | | _ | | | | | | | | | | | | |
| | | | | 5 | 21115 | 4 | | | | | × | × | × | × | <u>^</u> × | _ × | | _ | 7 | _ | <u>-</u> | 0 | | | |
| _ | | | | | 2 | - | | | | _ | | | | | | _ | | _ | | | | | | | |
| | | | | phases, beginning with pattern specification, and | | | | | | _ | _ | | | | _ | _ | | _ | | | _ | | | | |
| _ | | | | progressing through differentiation, how will | | | | | | | | | | | | _ | | _ | | | | | | | |
| | | _ | | gravity affect selected phases in animals that | | _ | | | _ | _ | | | | | | _ | _ | | | | | | | | |
| | | | _ | represent different species and phyla? | | | | | | _ | | | | | | | _ | | | | | | | | |
| | | | | How will gravitational fields, particularly | | _ | | _ | | | | | | | | _ | _ | | | | | | | | |
| _ | | | | microgravity, disturb the precise coordination and | | | | _ | | | | | | | _ | | | | | | | | | | |
| | | | | postural control required in mating? | | | | | | | | | | | | _ | _ | | | | | | | | |
| | | | | - Will aquatic animals perceive and respond to | | _ | | | | | | | | | | | _ | | | | | | | | |
| | | | | oravity as do their terrestrial counterparts? | | _ | _ | | | | | | _ | | | _ | | _ | | | | | | | |
| | | | | Those animals which pursue different life stages | | _ | _ | _ | | | | | _ | | | | | - | | | | | | | |
| | | | | in both environments may be particularly valuable | | _ | | | | | | | | | | _ | _ | | | | | | | | |
| | | | | for study | | | _ | | _ | | | | | | | _ | | | | | | | | | |
| | | | | , | 21110 | | | | _ | | | × | × | × | × | _ × | - | _ | 2 | 2 | - | ა, 4 | | | |
| _ | | | _ | - | 0110 | ; | | | | | | | | | | _ | _ | _ | | | | | | | |
| | _ | | | circadian rhythms, both temporally and with | | _ | | | | | | | _ | | | _ | | | | | | | | | |
| _ | | | _ | respect to differentiation state? | | _ | _ | _ | _ | _ | _ | - | - | _ | - | • | • | • | | | | | | | |

CI=Environmental Health C2=Counterneasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Table 1

Critical Questions From All Life Sciences Division Discipline Science Plans

| CI C2 C3 C4 C5 C111 call | | | | | | | ŀ | . | | | | | | • | | | | | | | | | | | | | | | |
|--|--|---|---|--|---|----------|---|------------|----------------|---|---|-------------|------------|-----|---|---|---|---|----------|---|----------------|----------|-------------|---|----------|---------------------|------|-------|------|
| Control Guestion | - 1 | - 1 | - 1 | - 1 | | Quest# C | | - | 2 | 3 | 4 | 5 | 9 | ۲ | ۴ | H | ۲ | ; | Ŀ | Ľ | Ľ | Ŀ | Ŀ | Ľ | _ | | 1 | | |
| How does gravity affect organogenesis and the development of anatomical structures? Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular. | | | | How does gravity affect organogenesi development of anatomical structure — Are the gravity sensitive systems vestibular, proprioceptive, cardiovas | s and the s? (i.e. | 81117 | 4 | - | - | | - | | | × × | | | , | | <u>-</u> | 2 | - - | <u> </u> | | | _ | Group w/ 7, 8, 5 | | other | Disc |
| similarly sensitive to this stimulus in ontogeny? What structural and morphometric alterations will occur in the extracellular matrix, the connective tissue, and the musculoskeletal systems in long | | musculoskeletal) of young and adult an similarly sensitive to this stimulus in What structural and morphometric alte occur in the extracellular matrix, the tissue, and the musculoskeletal systems. | musculoskeletal) of young and adult an similarly sensitive to this stimulus in What structural and morphometric alte occur in the extracellular matrix, the dissue, and the musculoskeletal systems. | rrusculoskeletal) of young and adult an similarly sensitive to this stimulus in What structural and morphometric alte occur in the extracellular matrix, the tissue, and the musculoskeletal systems. | imals antogeny? rations will connective s in long | 81118 | 4 | *** | , - | - | - | ν | × | × | × | × | | × | | | | - | - | | <u> </u> | ø, L | | | |
| term spaceflight? How will this result in altered differentiation cells, and in changed tissue composition? How do specific organs and tissues respond developmentally to altered gravity, as demonstrated by the expression of selected targgenes in transgenic mice with pre-determined genetic makeups? | — How will this result in altered differcells, and in changed tissue composition 5 * How do specific organs and tissues respondevelopmentally to altered gravity, as demonstrated by the expression of selections in transgenic mice with pre-deteringenetic makeups? | How will this result in altered differcells, and in changed tissue composition From do specific organs and tissues respected organity, as demonstrated by the expression of selections in transgenic mice with pre-deter | — How will this result in altered differcells, and in changed tissue composition How do specific organs and tissues respondevelopmentally to altered gravity, as demonstrated by the expression of selegenes in transgenic mice with pre-deteringenetic makeups? | Term spaceringnt? — How will this result in altered differcells, and in changed tissue composition. How do specific organs and tissues responselopmentally to altered gravity, as demonstrated by the expression of selengenes in transgenic mice with pre-deteringenetic makeups? | ation of target | 6 | 4 | | | | | | × | | × | × | × | | | | | 8 | | - | | | | | |
| 5 * How will parent-young interactions be aftered the space environment? — Will hatching or parturition occur normally | 5 * How will parent-young interactions be atter the space environment? — Will hatching or parturition occur norm | 5 * How will parent-young interactions be attered the space environment? | How will parent-young interactions be after the space environment? Will hatching or parturition occur norm | How will parent-young interactions be attered the space environment? Will hatching or parturition occur norm | . <u>=</u> ~ | 81110 | 4 | _ | | | | | <u>×</u> _ | | × | × | × | × | 1 | | | 8 | - | - | დ. 4 | , s | 7, 8 | | |
| - What will be the effects on lactation, suckling and related parent- young bonding mechanisms? In the period of rapid post-natal growth, which systems are the most sensitive to altered gravity perturbations? | What will be the effects on lactation, sand related parent- young bonding mechan In the period of rapid post-natal growt systems are the most sensitive to altered perturbations? | What will be the effects on lactation, sand related parent- young bonding mechan In the period of rapid post-natal growt systems are the most sensitive to altered perturbations? | What will be the effects on lactation, sand related parent- young bonding mechan In the period of rapid post-natal growt systems are the most sensitive to altered perturbations? | What will be the effects on lactation, sand related parent-young bonding mechan in the period of rapid post-natal growt systems are the most sensitive to alterederurbations? | uckling nisms? h, which d gravity | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 What are the effects of gravity, in concert particularly with life in closed ecosystems, on sexual maturation? | * | * | * | What are the effects of gravity, in concert particularly with life in closed ecosystems sexual maturation? | uo | 81111 | 4 | | | | | | _×_ | | × | × | × | × | | | - | ~ | | | | | | | |

CI=Environmental Health C2=Countemeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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| Science Plans |
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| 8 | <u> </u> | 2 | CS | C1 C2 C3 C4 C5 Critical Question | Quest# | 5 | <u> </u> | 2 | 1 | ٠ | 1 | T | <u>}</u> | | + | ┶ | _ | + | 1 | 1 | 1 | 1 | | |
| | | 4 | v | s gravity produce responses in cultured a mimic those seen in chronologically aged use isolated from accelerated aging es, and senescent cells in vitro? In de-limiters of lifespan have relevance to onal effects? The joint effects of radiation and avity? do neoplasms common to chronological late to limitation of cell lifespan and bility to abnormal growth regulation under oravitational fields? | 811113 | 4 0 | - | - | - 2 | ტ | × × | × × × × | × × | × × | × | | | 2 - 2 | | 4, 00 | | ח | | |
| ᆚ | Т | \prod | 丄 | Biology(Dev)/N | euroscience/Gravity | /Gra | vity | S | Sensing | 5 | | | | | Ì | ŀ | Ţ | ł | } | _ | | | - | |
| | | | 2 | rity a continuum in terrus/response? | 8IVa1 | 4 | | | | | × | | | × | × | | | - , | - : | | 5 5 | | | |
| | | | 2 | 5 • What is the role of gravity in the evolution of animal gravity sensors? | 8IVa2 | 4 | | | | | × > | × > | × × × × | × × | × × | | | <u></u> | <u>_</u> | - 0 80 | <u>></u> | | | |
| | | | S. | What are the basic properties and fundamental mechanisms that permit gravity sensors to adapt to an attered g-environment? | 817a3 | 4 | | | | | <u> </u> | | | | < × | | | | | | | | | |
| | | | 22 | 5 - Will animals bred for many generations in attered-g show phenotypically different gravity sensors? | 8IVa4 | 4 | | | | | | | | | , | | | | | | | | | T |
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Table 1

Critical Questions From All Life Sciences Division Discipline Science Plans

| duestion he specific role of calcium in informating by gravity sensors, and has this role evolutionary expansion or diminutio econd messengers and neurotransmit eural processing of information similal ecies, or is there evolutionary selection for modulatory influences? evelopmental Biology(Dev)/Nerelationship between the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the evolution of ille terrestrial forms and the benefit and gravity sensor formation about linear acceleratory ng on the system? What is the basis ing? mathematical interpretations and simulations of gravity sensor processing that can provide insights y important questions for experiment ag scarce altered-g force resources? The potential spinoffs in this work for understanding of other systems by us nethods, or for computer technology? Kundamental principle of gravity senso processing that bemits determination | C1 C2 C3 C4 C5 Critical Question 5 | 9019106 | Cr1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 1 2 1 2 1 | 4 × × × × × × × × × × × × × × × × × × × | 3lVb3 4 X | pue | 4 | Nc2 4 X X X X X X 1 1 1 1 1 8 | Vc3 | 4 4 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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| <u>v</u> × ∞ | <u>≯ ਲ ≯ ਲ</u> | <u> </u> | 5 • Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? | 81Vd5 | 4 | | | | | | × | <u>×</u> | <u> </u> | <u> </u> | < | | | | | · | | | | | |
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| 5 2 a g | <u>a</u> <u>a</u> | ह है ठ | 5 • Does development of a gravity receptor in an attered-g environment affect the ability of the animal to mature and reproduce? | 81761 | 4 | | | | | | × | <u>×</u> | <u>×</u> | <u>×</u> | <u> </u> | | | <u> </u> | | | |) | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

Table

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| | S. | What is the role of gravity in the regulation of | circadian rhythms? | - | on the generation, expression (period, phase, | amplitude and/or waveform) and entrainment | circadian rhythms? | 1 | 1 | synchronizing agents (light, exercise)? | 1 | circadian rhythms? | _1 | acro | 8 | 1 | the | gra | org | 5 - How does gravity affect interactions between | <u>Q</u> | j | 5 How does gravity affect interactions between | <u>ਲ</u> ਵ | <u> </u> | ပီ | 8 3 3 5 |
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| | | | | | environmental factors to control regulatory physiology and behavior? | | | | | | | | | | | | | | | | , | | • | | |
| | | | | ب | 5 * What is the role of gravity in the regulation and | 8Vb11 | 4 | | | | | × | × | × | × | × × | | | | | _ | <u>` </u> | , | | |
| | | | | | onset of reproductive cycles (vaginal opening, puberty, estrus cycles, fertilization, pregnancy, | | | | | | | | | | | | - | | | | | | | | |
| | | | | | etc.)? | | | | | | | | > | > | > | | × | | _ | 0 | | _ | ω. 4. | 10 | |
| | | | | <u>ئ</u> | 5 ' Is gravity necessary for sex behavior? If so, how does oravity affect it and what are the | 8Vb12 | 4 | | | | + | <u> </u> | < | < | < | | <u> </u> | | | l | | | • | | |
| | | | | | mechanisms? | | | | | | | | | | ; | ; | | | | • | Ţ | | _ | | |
| | | | | เก | 5 * Are regulatory responses to an artificial 1-9 | 8Vb13 | 4 | | | | | <u>×</u> _ | <u>×</u> _ | × | × | × | | | <u>-</u> | <u>-</u> | | | r | | |
| | | | | | environment in space equivalent to 1-g responses on Earth? | | | | | | | | | | | | | | | | | | | | |
| | | | | ŭ | F * Is 24 hour per day 1-d exposure necessary to | 8Vb14 | 4 | | | | _ | × | × | × | × | × | _ | | = | | | | 4 | | |
| | | | | | maintain normal regulatory function? If not, what | | | _ | | | | | | | | | | | | | | | | | |
| | | | | | is the minimum time? What are the optimal | | | | | | | _ | | | | | | | | | | | | | |
| | | 4 | _ | 4 | presentation characteristics of the Commission | 1 | 1 | - |] ; | 1 | 1 | 1 | } | - | |] | l | | | | | | | | |
| | | | | | Cell, Developmental Biology(Dev)/Support | | Structures, | Š, | š | Ē | BIOMINGRAIIZAUON | 2 | 5 | - | | | } | \vdash | ŀ | \downarrow | L | | | | |
| <u> </u> | 4 | 6 | _ | ╀ | Is musculoskeletal growth, development, and | 8V11 | 2 3 | _ | - | - | 6 | × | × | × | × | × | × | | _ | _ | | | , ', ', | x 0 | |
| | | | | | function compromised during spaceflight and can | | _ | | | | - | <u> </u> | | | | | | _ | | | | | | | |
| | | | | | they readapt upon return to Earth? The structure | | _ | | | | | | | | | | | | | | | | _ | | |
| | _ | | | | and functional systems that should be examined | | | | | | | | | | | | | _ | | _ | | <u>-</u> | | | |
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| _ | | | _ | _ | (4) intervertebral discs, (5) the architecture of | | | | | | | | | | | | | | | | | | | | |
| | | _ | | | the connective tissues of the body and (6) | | | | | | | | | | | | | _ | | | | | | | |
| | | | | | musculoskeletal innervation. | | | | | | | | | | > | > | -> | | _ | _ | - | _ | - | | |
| | 7 | <u>ო</u> | | | What are the systemic, local, cellular, and subcellular mechanisms involved in adaptation to attered gravity especially bioenergetics and | 8VI2 | 4 ω | - | <u>-</u> | | m | | <u> </u> | <u> </u> | < | < | < | | · | | | | | | |
| | | | | | associated processes and cell-to-cell interactions | | _ | _ | _ | _ | | - | - | - | - | - | - | • | • | • | • | i | | | |

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Table 1

Critical Questions From All Life Sciences Division Discipline

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| <u> </u> | Quest# | 8VI3 | 8V14 | 8VI6 | 8VI7 | 8/19 | 8VI10 | 8VI12 | 8VI15 | 3V/16 |
| DIVIS | Question | 5 Is the musculoskeletal cyto-architectural 8V13 organization and responsiveness to physiological and mechanical stimuli attered by gravity? | altered | | What are the transduction mechanisms that couple 8VI7 mechanical stress to musculoskeletal mass and strength? What are the activation and force development processes of muscle and bone cells? | What signals the musculoskeletal adaptation to spaceflight? Are the signals the same as those found in biomechanical unloading on Earth? | What local changes occur in the musculoskeletal 8VI10 system in response to changes in stresses, strains, and strain rates? | Is the relationship between muscle and bone necessary for an integrated response to attered gravity or do the systems respond independently? | Do various risk factors(e.g., age, gender, species, 8VI15 strain (race), nutrition) modulate the musculoskeletal response to altered gravity? | **Mhich mechanisms of adaptation of the musculoskeletal systems of rats, monkeys, and humans to altered gravity are similar and which mechanisms are different? |
| DIVIS | Question | ological /? | the to altered n tissues? | | | _ | letal | , , , | cies, | |
| DIVISION | Question | ological /? | What is the role of fluid redistribution in the response of the musculoskeletal system to altered gravity and how does gravity impact the homeostasis of fluid compartments within tissues? | What are the biochemical pathways responsible for synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to altered gravity? | What are the transduction mechanisms that couple mechanical stress to musculoskeletal mass and strength? What are the activation and force development processes of muscle and bone cells? | What signals the musculoskeletal adaptation to spaceflight? Are the signals the same as those found in biomechanical unloading on Earth? | letal | Is the relationship between muscle and bone necessary for an integrated response to attered gravity or do the systems respond independently? | cies, | eys, and nd which |
| DIVIS | 2 C3 C4 C5 Critical Question | ological /? | What is the role of fluid redistribution in the response of the musculoskeletal system to altered gravity and how does gravity impact the homeostasis of fluid compartments within tissues? | What are the biochemical pathways responsible for synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to altered gravity? | What are the transduction mechanisms that couple mechanical stress to musculoskeletal mass and strength? What are the activation and force development processes of muscle and bone cells? | _ | letal | Is the relationship between muscle and bone necessary for an integrated response to attered gravity or do the systems respond independently? | cies, | eys, and nd which |

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Critical Questions From All Life Sciences Division Discipline Science Plans

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| C2 C3 C4 C5 Critical Question | CELSS — LIFE SUPPORT, BIOLOGICAL/Biomass | Can crop plants produce sufficient edible biomass extra-terrestrially to support human crews? The following constraints should be considered in studying this question: - Closed environments - Recycling - Limited space - Gravity effects - Phytogenic volatile compounds and other trace contaminants - Adventitious biota (microbial and other) What conditions are required to optimize the food generating and water recycling capacity of crop plants? The following factors represent the minimum that should be considered in studying this question: - Light quantity, quality, periodicity, gas composition and density - Root environment: substrate, nutrients, volume, temperature, etc Aerial environment: gas composition and pressure, temperature, planting density, etc. | What are the effects of adventitious biota (microbial and other) over long periods in a CELSS? | What robotic and automated procedures should be developed for planting, growing, and harvesting of crop plants? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Table 1

Critical Questions From All Life Sciences Division Discipline Science Plans

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| 2 | • | र | 3 | Clos Ca Cacitical Question | Quest# C | ပ | 1 | 2 | 3 | 4 5 | 9 | 1 | <u> </u> | 6 | 100 | = | 는 | 1 | 415 | 146 | [- | ŀ | _ | | | | Г |
| 4 | ₹ | | | How can molecular genetic technology, including germplasm screening, be used to develop crop cultivars better fit for CELSS use in space? (for example) | 9a6 | е | 2 | - | 60 | 2 | - | × | ă | | | | | - | | - 0 | | | <u>ئ</u> و | 10, 11 | | Disc | o l |
| | | | - | Improve nutrient quality and bioavailability Reduce natural toxicants Optimize plant architecture | | | | | | | | | | | | | | | | | | | | | | · | |
| | | 4 | | What is the potential for using the following alternative food sources in a CELSS? | 9a7 | 8 | 8 | - | 2 | <u>ო</u> | | × | Ħ | × | | <u>×</u> | | | | 2 | | - | 6, 1 | 10, 11 | | | |
| | | | | Animals (aquatic and terrestrial, vertebrate and invertebrate) | | | | | | | | | | | | | | | | | | | | | | , | ' |
| | | | | - Fungi - Ractaria | 1 | | | | | | | | | | - | | | | | | | | | | | | |
| | | | | Non-traditional higher plants | | | | | | | | | | | | | | | | | | | | | | | |
| | | | - | Synthetics Cens | | | -, | | | | | | | | | | | | | | | | | | | | |
| | | | | CELSS - LIFE SUPPORT, BIOLOGICAL/Food | Processing | - E | ┧╻ | 1 | - | - | _ | | | 1 | + | \dashv | 4 | _ | | | 7 | \top | | | | | |
| <u> </u> | - | 4 | | ٥ | 998 | 2 | | 9 | 10 | - | - | <u>></u> | | | \vdash | 1 | - | | Ĺ, | Į, | T, | + | | | | | |
| | | | | rat | | | | - | <u> </u> | - | | | | | - | <u><</u> | | | - | | | - | 9, 4, | , 6, | 6,7,9,10 | _ | |
| | | | <u>'</u> | - Caloric requirements | | | | - | | | | | | _ | | | | | | | | | | | | | |
| | | | 10 | Will the nutritional requirements of the crew change and require modified diets over time of | | | | | | | | | | | | | | | | | | | | | | | |
| | | | <u>#</u> | flight | | _ | | | | | | | | _ | | | | | | | | | | | | | |
| | | | 1 1 1 | Fluid requirements Distribution of the macro nutrients (protein, | | | | | | | | | | | | | | | | | | | | | | | |
| | | | <u> </u> | carponyorate, liptd) — Fiber and micronutrient requirements | | | | | | | | | | | | | | | | | | | | | | | |

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Table 1

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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| \ | <u> </u> | - | 1 7 | 696 | 2 2 | 2 | - | 2 | - | × | × | × | | × | _ | | _ | | <u>-</u> | _ | э, <u>ө</u> , | . 10 | | |
| | 4 | | | | | | | | | | | | | | | | _ | | | | | | | _ |
| | | | Some criteria include: | | | | | | | | | | | | | | | | | | | | | |
| - | | | - Safety and freedom from toxic substances and | | | | | | | | | | | | | | | | | | | | • | |
| | _ | | infectious agents | | | | | _ | | | | | | | | | | | | | | | | |
| | _ | | How will the crew respond to diet on a Mars | | | | | | | | | | | _ | _ | | | | | | | | | |
| | | _ | mission | | | | | | _ | | _ | | | | | | | | | | | | | |
| | | | Nutrient and attribute balance | | | | | | | | | | | | | | | | | | | | | |
| | | | Familiarity/cultural experience | | | | | _ | | | | | | | | | | | | | | | | - |
| - | | | — Taste/texture/color/shape | | | | | | | | | | | | | | | | | | | | | |
| | | | Flexibility in preparation methods | | | | | | | | | | | | | | | | | | | | | |
| _ | | _ | Cacking (time complexity atc.) | | | | _ | | - | _ | _ | | | _ | _ | | _ | | | | | | | |
| | _ | - | - COUNTIE (IIIIIE, COTTIPIENTY), SEC.) | | _ | | | | _ | | | _ | | | | _ | | | | | | | | |
| _ | | _ | Seasoning (diversity of options) | | | | | | | _ | | | | _ | | - | | | | | _ | | | _ |
| | | | Compatibility with other menu items | | | | | | | | _ | | | | | | | | | | | | | _ |
| | | | Variety — | | | | | | | | | | | | _ | | | | | | | | | |
| _ | | _ | What food groups fulfill these requirements? | | | | | | _ | | _ | | | | | | | <u>-</u> | | | | | | |
| _ | | _ | - How can the biomass candidates be used or | | - | | | _ | _ | | | | | | | | | | | | | | | |
| | | | modified to achieve the desired requirements? | | | | | | | | | | | | | | | | | | | | | |
| | | | and broad blooms of the sales o | 0411 | 7 | ٧ | _ | 67 | - | <u>×</u> | | × | | | × | _ | - | = | <u>-</u> | _ | <u>က်</u> | 9, 10 | | |
| | 4 | <u> </u> | How stable in storage are todds cursidered in | | <u>-</u> | _ | | | | _ | | | | | | | | | | | _ | | | _ |
| _ | | _ | Mars mission and how can storage stability in | | | | | | | | | _ | | | _ | - | | | | | | | | |
| | | | space be increased? | | | | | _ | , | | | | | | | | _ | | | | | | | |
| | | _ | - What are the safety and quality considerations | | | | | | | | | | | | | | | _ | | | | | | |
| | | | of storage? | | | | | | . — | | | | | | | | | | | | | | | |
| | - | _ | What processes are feasible to use in a CELSS? | _ | | | | _ | | _ | _ | | | | | | | | | | | | | |
| | | | Are additives needed? If so, which ones? | | | | | | | | | | | | | _ | | - | | | | | | |
| | _ | | What are the storage/inventory requirements? | | | _ | | | | | | | | | | | _ | | | | | | | |
| | | | - For what types of foods will storage be | | | | | | - | | | | | | | - | | | | | | | | |
| | | | unnecessary? | | | | | | | | | | | | | | | | | | | | | _ |
| | | _ | — Is there a need for packaging? If so, which | | | | - | | | | | | | | _ | | | | | | | | | |
| | | | products will require it? | | _ | _ | | _ | _ | _ | _ | _ | _ | _ | _ | _ | - | _ | _ | _ | _ | | | - |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Cnücality
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| | Quest# | 9b 12 | 9613 | 9b14 9b165 | ste Processing | 9c168 | 9c17 |
| | C2 C3 C4 C5 Critical Question | What food processing and storage technologies will need to be developed for space application? — How will existing and new processing and storage techniques perform in the constraints of a CELSS environment? — What differences are there in product development for space compared to land-based activities? — What are the influences of processing. | and serving on — nutrient and attribute stability? — How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? Can edible foods and/or ingredients be derived from non-edible plant wastes? — What are the crop plant-specific limits of this canability? | How will non-recyclable materials be minimized in a CELSS program? How do the above nutritional questions apply to CELSS produced foods, used either as a nearly complete diet or as a supplement to struct food? | CELSS — LIFE SUPPORT, BIOLOGICAL/Waste | What are the processing requirements necessary to handle human wastes? What are the health and safety requirements for the waste treatment subsystem? | What are the processing requirements necessary to convert metabolic wastes into nutrients suitable |
| | S | | | | +++ | <u> </u> | <u> </u> |
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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| ۲ | ٢ | 12 | ٢ | Colcalcal Critical Question | Quest# | ū | 1 2 | ო | 4 | 5 | 9 | 7 8 | 6 | 읙 | Ξ | 121 | - 1 | 4 | 2 | 1617 | <u>°</u> | <u> </u> | Group W/ Ourer | | | . T |
| 1 - | - | 4 | - | What will be the limits of the composition of the | 9c18 | 6 | 2 1 | - | 2 | 2 | _ | × | | | | | | 7 | N | _ | | 3, 6 | | | | |
| | | | | processed waste streams with regard to the following parameters: | | | | | - | | | | | | | | | | | | | | | | | |
| | | | | Organic an inorganic materials Potentially toxic materials | | | | | | | | | | | | | | | | | | | | | | |
| | | 4 | : | What currently available waste treatment/nulregeneration technologies can be adapted to a | 9c19 | ဗ | 8 | 2 | 0 | 8 | | × | <u>×</u> | | | × | | | 7 | | - | <u>რ</u> | 9 | | | |
| | | | | CELSS use, and what technologies will need to be developed for space application? (Note question 16.8) | | | | | | | | | <u> </u> | | | | | | ŀ | | | | | | | |
| • | | 4 | | To what extent will micro-organisms used in a | 9c21 | 2 | 8 | 1 2 | N | 8 | | × | × | | | × | | | ٧ | | | <u>က်</u> | ဖ | | | |
| | | | | physico-chemical waste processor present an issue of performance degradation? | | | | | | | | | | | | > | | | | | | ď | y. | | | |
| - | | 4 | | What are the production rates and chemical compositions of the different waste streams that are to be processed in a CELSS? | 9c22 | ო | 0 | - | | 2 | | | × | | | < | | | | <u> </u> | <u> </u> | _ | , . | | | |
| | | 4 | | What can be done about food packaging, crop selection, etc., to minimize the amount of material that ends up in the waste streams? | 9c23 | ი | 8 | - | | N | _ | × | | | | | | N . | <u>N</u> . | | | | ، م | | | |
| • , | | 4 | | Can plant transpiration water qualify as potable and hygiene water? If not, what currently available water treatment technologies can be adapted to polish transpiration water in a CELSS, | 9c24 | ო | 8 | _ | | Ν | - | × | ^ | × | · · · · · · · · · · · · · · · · · · · | × | | | <u></u> | | | ກ້ | ٥ | | | |
| | J | | | and what technologies will need to be developed for space application? | | | | | | | | ; | | | | > | | <u>`</u> | | | | ٣. | y | | | |
| • | | | | What are the best technologies for recycling the water required for a Mars mission to acceptable potable and hygiene levels? | 9c245 | <u> </u> | 4 | 9 | - 2 | - | | × | × | | | <u> </u> | | | | | • | <u> </u> |) | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

| C1 C2 C3 C4 C5 Critical | CS Cr | C | itical Question | | | | - | ┢ | _ | - | | | ŀ | ŀ | - | | Ì | İ | | | | | | |
|--|---|---|---|----------------------|--------|----------|----------|-----|---|----------|---|----------------|---|--------------|------|----------|---|----------|-------------|--------------|----------|-----|-------|------|
| | | 7 | | Quest# | 5 | _ | 2 | 3 4 | 2 | 9 | 7 | 8 | 6 | 0 | 1 12 | 13 | 4 | 15 | 161 | 7 | 18 Group | Ì≩ | ette. | Disc |
| If the crop plants in a CELSS can be to the production rate demands for potal hygiene water, then what types and replants will be required, and what enconditions will these plants require? | If the crop plants in a the production rate di hygiene water, then v plants will be require conditions will these | If the crop plants in a the production rate do hygiene water, then y plants will be require conditions will these | If the crop plants in a CELSS can be used to meet the production rate demands for potable and hygiene water, then what types and numbers of plants will be required, and what environmental conditions will these plants require? | 9c25 | က | α | 2 | 2 | 7 | _ | × | × | × | | × | | | - 2 | - | - | | : { | | 3 |
| What currently available water treatment technologies can be adapted to recycling trivarious grades of water (hygiene, wash, e CELSS and what technologies will need to the developed for space application? | What currently availe technologies can be a various grades of wat CELSS and what tech developed for space a | What currently availe technologies can be a various grades of war CELSS and what tech developed for space a | What currently available water treatment technologies can be adapted to recycling the various grades of water (hygiene, wash, etc.) in a CELSS and what technologies will need to be developed for space application? | 9c56 | ო | N | <u>-</u> | N | 7 | | × | × | × | - | × | | | | | - | 9 | | | |
| What are the storage requirements for phygiene water in a CELSS? Consider: — Safety/redundancy — Control of microbial film on surfaces — Volume | What are the storage hygiene water in a CEI — Safety/redundancy — Control of microbis — Volume | What are the storage hygiene water in a CEI — Safety/redundancy — Control of microbis — Volume | What are the storage requirements for potable and hygiene water in a CELSS? Consider: — Safety/redundancy — Control of microbial film on surfaces — Volume | 9c27 | N | 8 | <u> </u> | Ν | Ν | - | × | - × | | | × | | | <u> </u> | | | ب ب | • | i | |
| 4 What will be the acceptability threshold: revitalized air in an operational CELSS? | What will be the acce revitalized air in an op | What will be the acce revitalized air in an op | s for | 9c28 | α, | <u>ဗ</u> | | - 7 | 8 | - | × | × | | | × | | | | | | 3, 6 | | | |
| What currently available air treatment technologies can be adapted to a CELSS what technologies will need to be devel space application? | What currently availat technologies can be act what technologies will space application? | What currently availat technologies can be act what technologies will space application? | use, and oped for | 9c29 | 2 | <u>e</u> | | ٥ | 7 | - | × | <u>×</u> × | | | × | | | <u> </u> | | | 9 | | | |
| What types and surface required to meet the prorective revitalized air and what do these plants require? | What types and surface required to meet the previtalized air and who do these plants required. | What types and surfac required to meet the revitalized air and wh do these plants requir | area of plants will be duction rate demands for environmental conditions | 0000 | ල ව | | <u>~</u> | 2 | N | | × | _ <u>×</u> | × | | × | | - | <u>N</u> | | <u>-</u> | (၁) | | | |
| CELSS - LIFE SU | 1 | 1 | LIFE SUPPORT, BIOLOGICAL/Sys | L/System Integration | graf | <u>.</u> | 4 | 4 | | | - | \dashv | 4 | | | \dashv | 4 | 4 | | _ | | | | Т |

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| Questa | 9431 | 60933 |
| Critical Question | What strategies or techniques exist for monitoring and control of the known or suspected possible causes of life support system instability? Consider: Pests or pathogens (disease) SMACS Toxicants produced by humans, by processing procedures, or by the plants themselves Atmosphere leakage Perturbations in environmental controls Radiation Microgravity Landiation in explain and algal fermentation systems Food variety What are the requirements for CELSS system design and operation to achieve safe and reliable operation? Address the following: Subsystem redundancy Interaction with Chemical - Physical regeneration | Alternative strategies for system monitoring and control - Failure of a subsystem Is a CELSS, because it operates within a limited volume and intense dynamics, subject to unknown or poorly characterized instabilities, such as chaotic behavior? |
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| 5 | છ | ខ | 3 | છ | C1 C2 C3 C4 C5 Critical Question | Quest#C | C + 1 | | 2 3 | 4 | 2 | 9 | 1 | 8 | 6 | 1011 | 113 | 13 | E | 14 | 16. | 1 | 100 | | - [] | | Г |
| - | | - | 4 | | What are the thresholds of system size (minimal) and system safety and reliability (maximal), and can these be extended in an integrated, controlled system? | 9434 | N | 0 | 2 | 8 | 8 | _ | × | | | | | - | • | 2 | | | | 3, 8, 1 | 11 ourse | or Uisc | υl |
| - | | • | 4 | | How can mathematical models be utilized to aid in system design, system simulation, and system operations? | 9635 | N | <u>ო</u> ; | - | -8 | N | - | × | | × | | × | | | | ~~ | | <u>რ</u> | œ, | Ξ | | |
| | + | | 4 | | What are the power requirements and launch mass and volume for an operational CELSS? | 9626 | ~ | _ 2 | <u>£</u> | Ν_ | N | - | × | | | | | | | , ~ | - | | က် | œ, | Ξ | | |
| - | | | 4 | | What robotic and automated procedures should be developed for control, monitoring, and operations? | 9437 | <u>ო</u> | - | <u></u> | - | 7 | _ | × | | × | | × | | | - | 2 | | | æ, | = | | |
| - | | 4 | _ _ | , | What sensors are required for automation of a CELSS? | 9038 | 0 | ω 4 | | 7 | 7 | _ | × | | × | | _× | | | - 2 | | | <u></u> છ | 8 0 | = | | |
| | | | | | CELSS - LIFE SUPPORT, BIOLOGICAL/Space | se Flight | ┪ | 1 | \dashv | 4 | | | 7 | 7 | - | - | 4 | | | 7 | \dashv | \dashv | ╁ | | | | |
| - | | 4 | | | What is the productivity, transpiration, and dry matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | 39 | 2 2 | 2 | - | 2 | - | - | × | | × | | × | | | 1 2 | - | - | ō, | 2, | | | |
| • | | 4 | | | What is the morphology and reproductive capability 9e40 of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for space bases? | | 8 | <u>N</u> | - | 0 | - | | × | × | <u>×</u> | - | × | | | - 2 | | | 10, | ., = | _ | | |
| - | | 4 | | _ = 0 | What countermeasures can be utilized if productivity or reproduction is significantly decreased? | 9641 | 2 | N | _ | 8 | - | <u>-</u> | × | _× | × | | × | | | _ ~ | | | | = | | | |

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Critical Questions From All Life Sciences Division Discipline Science Plans

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions From All Life Sciences Division Discipline Science Plans

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| - | | က | | | Do automated real-time systems exist to monitor 9f air quality/toxicology for Mars mission? | 9f5a | 2 | 6 | | | - | | × | | ` | ' | · × | | | 5 | 7 | | | 9 , | | S |
| - | | က | | | Do automated systems exist to monitor food safety/quality for Mars mission? | 9151 | က | - | _~_ | N | - | | × | <u>×</u> | | | × | | | | - 7 | - | <u>.,</u> | 9 | | |
| - | | е | | | Do systems exist to provide EVA/EHA capabilities 9fer required for Mars transit? | 9f6a | N | | ~ | 6 | - | - | × | × | | | | | 1 | - | - | | <u> </u> | 9. | | |
| - | · | 3 | | | Do systems exist to provide EVA/EHA capabilities 9ff required for Mars surface exploration? | 9166 | - | 2 2 | 2 | | | | × | | | | × | | | - | | | <u> </u> | 9 , | | |
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| <u>. </u> | 77 | ო | 4 | <u> </u> | What requirements should be placed on robotic and 10 human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | - | - | 8 | - | ო | - | É | × | × | | × | × | × | | 2 | 2 | - | | 13, 14 | | |
| - | · · | · · | 4 | | What provisions must be taken during the course of 10 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | 8 | 6 0 | | - | | ო | <u>ო</u> | × | _× | · · · · · · · · · · · · · · · · · · · | × | × | × | . | - 2 | ~ | | | | | |
| | \dashv | | | | EXOBIOLOGY/Cosmic Evolution of Biogenic | Compounds | ∦ § | <u>.</u> | | - | 1 | 1 | 1 | - | - | 4 | 1 | 1 | 1 | 1 | 1 | - | ╫ | | | |
| | | | 4, | | 5 • What is the degree of molecular complexity and its 11a1 evolution in circumstellar, interstellar, and protosolar environments? | a1 | | - | | | | <u>×</u> | × | × | ļ-, | × | × | | 2 | 2 | <u>-</u> | - | <u> </u> | | | T |
| | | | -C2 | 4 | What is the composition, structure, and inter-relationships between circumstellar, interstellar and interplanetary dust? | a2 4 | | | | | | _× | | × | · | | × | × | | - 0 | | | | | | |
| | | | ν. | • | What is the efficacy of chemical and physical processes in the ptotosolar nebula for altering pre-existing materials and producing new compounds and phases containing the biogenic elements? | 8 8 4 | | | | | | <u>×</u> | | _× | | | × | × | | <u> </u> | | | | | | |

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Table 1 Critical Division

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| | Question | 11a4 | position 11a5 | l | In terms of the fluxes of matter and energy that 11b1 maintain disequilibrium conditions, what universal metrics can be developed for assessing the potential of different microenvironments to support the origin and evolution of life? | What bounds do the energetics and dynamics of 11b2 accretion and core formation place on the time when surface temperatures became suitable for the occurrence of liquid water? | • What fluxes of intact organic compounds could have 11b3 been supplied to the Earth's atmosphere and surface waters by accretion of cometary or carbonaceous chondritic material? | • What geological settings were conducive to the 11b4 origin of life? | • What were the earliest products of the interaction 11b5 of liquid water or atmospheric gasses or both with crustal rocks? | • What minerals were available as potential chemical 11b6 catalysts in the boundary regions? |
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Table 1

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| | 1 | Then did different parts of the lach the surface of the Earth, etiming? | hat photochemical processes or mosphere, at the interfaces of the ceans and land, and in su | hat were the products and rat trogen fixation by photochemi ocesses? | hat was the nature of the ear cles of the biogenic elements id space scales did they opera | nder what conditions could me phoxide, rather than carbon di pplied as the dominant carbor rface? | hat redox couples could have semical free energy in various tive boundary regions over ti | what ways was Earth unique d Venus, in its ability to evolv drosphere? | what extent has chemical evigenic elements and compound nets other than Earth, and wiferent courses? | nat evidence is there for the mpounds of abiotic origin in luding Earth? | w did carbon chemistry leastems? |
| | 1 | When did different parts of the sunlight spectrum reach the surface of the Earth, and what influenced the timing? | What photochemical processes occurred in the atmosphere atmosphere with oceans and land, and in surface waters? | What were the products and rates of carbon and nitrogen fixation by photochemical or other processes? | What was the nature of the earliest geochemical cycles of the biogenic elements and over what time and space scales did they operate? | Under what conditions could methane or carbon monoxide, rather than carbon dioxide, have been supplied as the dominant carbon source at Earth's surface? | What redox couples could have supplied sources of chemical free energy in various geophysically active boundary regions over time? | In what ways was Earth unique, relative to Mars and Venus, in its ability to evolve and maintain its hydrosphere? | To what extent has chemical evolution of the biogenic elements and compounds occurred on planets other than Earth, and why did it take different courses? | What evidence is there for the presence of biogenic compounds of abiotic origin in planetary materials, including Earth? | How did carbon chemistry lead to self-replicat systems? |
| | 1 | 5 * When did different parts of the sunlight spectrum reach the surface of the Earth, and what influence the timing? | • | | • | 5 • Under what conditions could me monoxide, rather than carbon d supplied as the dominant carbor surface? | | | • | What evidence is there for the compounds of abiotic origin in including Earth? | How did carbon chemistry les |
| | C4 C5 Critical | 5 * When did different parts of the reach the surface of the Earth, the timing? | What photochemical processes atmosphere, at the interfaces o with oceans and land, and in su | | | 4 | | | | | |
| | C3 C4 C5 Critical | 5 When did different parts of the reach the surface of the Earth, the timing? | • | | • | 4 | | | • | | - |
| | C4 C5 Critical | 5 * When did different parts of the reach the surface of the Earth, the timing? | • | | • | 4 | | | • | | - |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions From All Life Sciences Division Discipline Science Plans

Table 1

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| | Life | In what ways have physical changes in the planetary surface environment influenced both the rate and the direction of early microbial evolution? | What is a geological time scale for major events in biological evolution? | How have the evolving biota, in turn, modified and modulated their environments over time? | What are the biochemical and genetic properties of the universal ancestor of all life and from these properties the characteristics of its environment? | What is the evolution of physiology and metabolism within the eubacteria, archaebacteria, and eukaryotes by means of molecular phylogeny and detailed comparative biology? | ttempt to with Earth? | isms and | ed Life | rical | = |
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| C2 C3 C4 C5 Critical | EXOBIOLOGY/Early | In what ways have physical changes in the planetary surface environment influenced both rate and the direction of early microbial evolu | What is a geological biological evolution? | How have the evolving biota, in turn, modi modulated their environments over time? | What are the biochemical and genetic properties the universal ancestor of all life and from these properties the characteristics of its environme | What is the evolution of physiology and me within the eubacteria, archaebacteria, and eukaryotes by means of molecular phyloged detailed comparative biology? | Related to the above, what has been the attemp integrate data on physiological evolution with geological data indicating the course of environmental development of the early Earth? | What are the simplest biochemical mechanisms structures that can carry out the various necessary functions of a living system? | EXOBIOLOGY/Evolution | What is the correlation between the historical pattern of biological evolution among complex fossil organisms and geological record of environmental change? | What is the history of effects on biological evolution that have been exerted by extraterrestrial phenomena? |
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Critical Questions From All Life Sciences Division Discipline Science Plans

| 5 | 읽 | 8 | 쥣 | C1 C2 C3 C4 C5 Critical Question | Quest# | 5 | - | 2 3 | 4 | 5 | 9 | | 80 | 9 | 0 | E | 2 | 3 17 | 4 15 | 19 | 1-1 | 18 | Group | Group w/ other | ا ا |
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| | | 4 | * | The highest priority in the category requiring flight missions is accorded to studies of Mars. — Conduct chemical, isotopic, mineralogical, sedimentological, and paleontological studies of Martian surface materials at sites where there is evidence of hydrologic activity in any early clement epoch, through in situ determinations and through analysis of returned samples; of primary interest are sites in the channel networks and outflow plains; highest priority is assigned to sites in which there is evidence suggestive of water-lain sediments of the floors of canyons as in the Valles Marineris syste, particularly Hebes and Candor chasmata, and — Reconstruct the history of liquid water and its interactions with surface materials on Mars through photogeologic studies, space- based spectral reflectivity measurements, in situ measurements, and analysis of returned samples? Look for extant life (does it exist?) on Mars — Microenvironments exist? | 11415 | ω ω 4 | | C C | | _ | _ | × | | | | | × | | 10 | <u> </u> | - | <u></u> | 13, 14 | | |
| \dashv | 4 | 4 | \dashv | TOP-LEVEL COUNTERMEASURES | | ĺ | | | | | | | | | | | | | | 1 | 1 | | | | |
| 0 | • | | | Do we need artificial gravity countermeasures to protect from physiological deconditioning of a mission to Mars? | 12 1 3 | <u>-</u> | - | 2 | | - | - | × | × | <u>×</u> | <u>×</u> | × | | | - | 2 | - | | 2, 3, 6 | | |
| 5 | | | | How should artificial gravity be applied in terms of g-load, rotation rate, and intermittent versus continuous exposure? | 12 2 3 | 9 | 9 | 2 | | - | _ | × | × | × | × | _× | | | _ | 8 | | - | 2, 3, 6 | | |

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TABLE 2

CRITICAL QUESTIONS LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- 1 = Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- 3 = Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- 4 = Science Specifically enabled by Moon and/or Mars Missions.
- Basic Research Not Directly Applicable to Moon and/or Mars Missions.
- Indicates primary category of application.

CRITICALITY

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| 1. | Science Readiness Levels |
|-------------|--|
| 1. | Only folklore of practitioners and anecdotal data available |
| | 2 Basic scientific concept formulated |
| | Ground models developed, flight validation required |
| | 4. Flight validation performed |
| | 5. Countermeasures identified |
| | 6 Countermeasures tested |
| | 7. Operational requirements established |
| 2. | Technology Readiness Levels |
| 5. - | Technology need identified |
| | Technology and conceptual solution available |
| | 3. Component and/or breadboard validation in laboratory |
| | environment exist |
| | 4. Flight validation performed |
| | 5. Systems/subsystem prototype demonstration in a relevant |
| | ground or space environment completed |
| | System prototype demonstrated in a space environment |
| | 7. Actual system completed and flight qualified through test an |
| | Demonstration |
| | 8. Actual system "flight proven" through successful mission |
| | operations |
| ı | Schedule (information required by) |
| _ | 1. = Near term < 5 years |
| | 2. = Mid term 6-10 years |
| | 3. = Far term > 10 years |
| L. | Effort Required |
| •• | 1. = Substantial |
| | 2 = Moderate |
| | 3 = Low |
| | Defined Sequence (Clearly defined sequential path for scientific |
| - | investigation exists) |
| | 1. = Yes |
| | <u> </u> |

Parallel/Alternative Path (are parallel or alternative pathways

Ground-based research required

Program recearch

Spacelab would be used for research Spacelab needed for Extended Duration Orbiter

Space Station Freedom would be used

appropriate)

Ground-based

Soacelab

EDO

SSF

7.

No

| althy | lives upon r | eturn to earth. |
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| 10. | Centrifuge | |
| | х = | SSF Centrifuge Facility would be used |
| 11. | Free Flyer | · · |
| | x = | Free flyer biosatellite |
| 12 | Luner Base | |
| | x = | Lunar base would be used |
| 13. | Robotic Expl | |
| | X = | Robotic explorer would be used |
| 14. | Other Requir | |
| | x = | Requirement for flight resources other then those identified in 8-10 |
| 15. | Flight Validat | ion Required |
| | 1. = | Flight validation required |
| | 2 | Not required |
| 16. | Facilities Suf | ficient |
| | 1 | Current ground facilities (NASA Centers, Universities |
| | | and provide industry) are sufficient. |
| | 2 = | Current ground facilities insufficient |
| 17. | Community S | |
| | 1. = | There is a sufficient scientific community already |
| | | committed or recruitable |
| | 2 = | Scientific community is insufficient |
| 18. | Attract New (| |
| | 1. = | Activity will attract new scientists |
| _ | 2 = | Activity will not attract new scientists |
| 19. | | ther disciplines (can this activity be grouped with |
| | - | ifferent life science disciplines?) |
| | 1 | No, cannot be grouped |
| | 2 - | Do not know at this time |
| | 3 | Behavior, Performance and Human Factors |
| | 4 = | Regulatory Physiology |
| | = | Cardiopulmonary Environmental health |
| | _ | Musculoskeletal |
| | 7. = | Neuroscienos |
| | _ | Radiation Health |
| | 10. = | Cell and Developmental Biology |
| | 11. = | Plant Biology |
| | 12. = | Life Support |
| | · = | Fire aribbar |

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| _ | 9 6 | | | | tors should be considered (e.g. | 142 | - | 2 | <u>۳</u> | - | ၉ | 6 | × | × | × | | _ | × | | | 1 | - | - | 2 | | |
| <u>. </u> | | | | | ē | | | | | | | | | | | | | | | | | | | | | |
| | | | | | when allocating functions between humans and machines? | | | | | | | | | | | | | | | | | | | | | |
| • | <u>_</u> ო | | | | What are the acceptable numbers and kinds of | 4b1 | - | 5 | -2 | 7 | - | _ | × | × | × | | | × | | | - | - | _ | _ | 10 | - |
| | | | | | microorganisms in air, water, food, and surfaces? | | | | | | | | | | | | | | | | | | | | | |
| * | 8 | 4 | | | For a given mission, what are the fluxes of GCR in | 7a1 | - | 3 | 5 | N | _ | 2 | ~ | | | | | | | × | 2 | 2 | | 2 | - | |
| | | | | | interplanetary space as a function of particle energy, EET, and solar cycle? | | | | | | | | | | | | | | | | | | | | | |
| * | 2 | | 5 | 5 | What are the maximum flux, the integrated | 7a4 | - | 2 | <u> </u> | _ | က | Œ | × | | | | | | | × | 2 | _ | _ | 2 | - | |
| | | | | | fluence, and the probability of large Solar Particle Events (SPE) during any mission? | | | | | | | | | | | | | | | | | | | | | |
| * | | | | | What will the radiation environment be within the | 7a8 | - | 7 | 4 | | ო | က | | × | × | | × | × | × | | N | _ | _ | _ | | |
| | | | | | space vehicle and what factors influence the flux, | | | | | | | | | | | | | | | | | | | | | |
| | | | | | energy, and linear energy transfer spectra of the radiation? | | | <u></u> | _ | | | | | | | | | | | | | | | | | |
| | | | | | | 1 | | _ | <u>,</u> | <u> </u> | | _ | <u> </u> | > | <u> </u> | | <u> </u> | <u> </u> | > | | 9 | - | | Ţ | | |
| - | | | | | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events he improved? | ก ช | _ | - | | | | | < | <u> </u> | | | < | . | . | | ı | | | | | _ |
| • | | | Ľ | u | What is the relative biological effectiveness of | 7f3 | | 2 | 4 | | | Ž | × | | | | | | | | 2 | 2 | _ | _ | - | |
| | | |) | , | different types of radiation for the relevant | | | | | | | | | | | | | | | | | | | | | |
| * | | | | | What should be the radiation dose limits for manned | 7a1 | | 7 | 4 | | _ _ | <u> </u> | × | | | | | | | | 8 | Q | _ | _ | _ | |
| - | <u> </u> | | | | deep space missions? | | | | - | | | | | | | | | | | | | | | | | |
| + | 7 | | ις. | 2 | What is the probability of cancer as a function of | 793 | _ | 7 | 4 | _ | _ | <u> </u> | × E | | | | | | | | N | ο _ι | _ | - | <u>-</u> | |
| | | | | | dose, dose rate, radiation quality, gender, age at | | | | | | | | | | | _ | | | | | | | | | | |
| | | _ | | | exposure, and time after exposure? What is the | | | | | | | | | | _ | | | | | | | | | | | |
| | | | | | effect of GCR at different stages of the | | | | | | | | | | | | | | | | | | | | | |
| | | | | | carcinogenesis process? | | | | _ | | - | \dashv | \dashv | ┥ | \dashv | _ | \dashv | 4 | 4 | _ | | 4 | ┛ | 4 | | |

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|--|--|--|--|---------------------------------------|--------|-----|-------------|----------|----------|---|-----------------|----|---|---------------|---------|-------------|-----|-----|---|-----|--------------|--------------|---------|-----|--------|------|---|
| How stable in storage are foods considered for Mars mission and how can storage stability in | | How stable in storage are food Mars mission and how can sto | How stable in storage are food Mars mission and how can sto | s considered for rage stability in | | T | 3 | T | <u>ო</u> | - | - - | ×_ | | | | - × : | - | - | - | | | | 9, 9, | 2 0 | Je Ino | UISC | |
| space be increased? - What are the safety and quality consideratio of storage? | ₫ " | ₫ " | ₫ " | ality considerations | | | | | | | | | | - | | · · · · · · | | | | - | | | | | | | |
| What processes are feasible to use in a CELSS? Are additives needed? If so, which ones? | What processes are feasible to Are additives needed? If so, | - What processes are feasible to Are additives needed? If so, | What processes are feasible to Are additives needed? If so, | o use in a CELSS? Which ones? | | | | | | | | | | | | | | - | | | | | | | | | |
| What are the storage/inventory requirement For what types of foods will storage be unnecessary? | What are the storage/invent For what types of foods will sunnecessary? | What are the storage/invent For what types of foods will sunnecessary? | What are the storage/invent For what types of foods will sunnecessary? | ory requirements? | | | | | | | | | | | | | | | | | | | | | | | |
| - Is there a need for packaging? If so, which products will require it? | - Is there a need for packaging? products will require it? | - Is there a need for packaging? products will require it? | - Is there a need for packaging? products will require it? | If so, which | | | | | | | | | | | | | | | | | | | | | | | |
| What food processing and storage technologies need to be developed for space application? How will existing and new processing and storage techniques perform in the contesting | | What food processing and storage ineed to be developed for space approximation will existing and new processions reform in the | What food processing and storage ineed to be developed for space approximate the will existing and new processorable techniques perform in the | Mil . | 9b12 | 4 | <u> </u> | | α | _ | _ | × | | × | <u></u> | × | ··· | | - | - | - | + | დ | 0 | | | |
| CELSS environment? — What differences are there in product development for space compared to land-based | CELSS environment? — What differences are there in prodevelopment for space compared to | CELSS environment? — What differences are there in prodevelopment for space compared to | CELSS environment? — What differences are there in prodevelopment for space compared to | duct | | | <u> </u> | | | | | | | | | | | | | | | | | | | | |
| activities? — What are the influences of processing, cookir | activities? What are the influences of proces | activities? — What are the influences of proces | activities? What are the influences of proces | sing, cooking, | | | | ·· | | | | | | | | | | | | | | - | | | | | |
| - How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? | — How can processing and cooking tused to modify and improve the accitods offered the crew? | — How can processing and cooking tused to modify and improve the accidods offered the crew? | — How can processing and cooking tused to modify and improve the acc foods offered the crew? | Tbute stability? | | | | | | | | | | | | · | | | | | | | | | | | |
| What are the processing requirements necessary to handle human wastes? What are the health and safety requirements for the waste treatment subsystem? | What are the processing requirement to handle human wastes? What are the safety requirements for the waste to subsystem? | What are the processing requirement to handle human wastes? What are t safety requirements for the waste t subsystem? | What are the processing requirement to handle human wastes? What are t safety requirements for the waste tsubsystem? | | 9c168 | _ 0 | _ ო | | 8 | N | - | × | × | | | × | | | - | α | - | - | 9, 9 | | | | |

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Table

Critical Questions Listed by Category and Criticality

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| Quest# Cr 1 | Can the physico-chemical regenerative 99425 1 2 technologies and processes required for a Mars mission life support system function in the space environment? Consider: — Maintenance of liquid-gas interfaces (e.g., for nutrient delivery) — Transfers and separations of liquids, solids, and gases — Combustion What is the composition of air, water, and spacecraft systems and how is it monitored to assure crew health safety and performance? Can safe and sufficient supplies of water and air be 9f1a 1 7 provided for the trip/stay to/at Mars? Do current expendable systems exist to provide safe | and sufficient supplies of water and air for the Mars mission? Do systems exist to provide EVA/EHA capabilities 9f6b required for Mars surface exploration? | What requirements should be placed on robotic and 10 1 1 7 human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? What are the requirements for adequate quality of 1c1 2 3 | ds s? ical 161 2 1 |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Table 2

Critical Questions Listed by Category and Criticality

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| Question | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight conditions? | What are the effects of chronic exposure to ultrafine and larger (respirable and nonrespirable) particles on crew health, safety, and performance? | What approaches may be used when insufficient 4a7 data are available to allow prediction of acceptable exposure levels? | What is the effect of space flight on all 4b2 microorganisms? | What technology is available to identify microorganisms in crew and environmental (air, water, surfaces) specimens. How are microorganisms controlled by anti-microbial procedures? |
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| Question | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight conditions? | | | | What technology is available to identify microorganisms in crew and environmental (air, water, surfaces) specimens. How are microorganisms controlled by anti-microbial procedures? |
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| | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight conditions? | | | | What technology is available to identify microorganisms in crew and environmental (air, water, surfaces) specimens. How are microorganisms controlled by anti-microbial procedures? |

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Critical Questions Listed by Category and Criticality

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| _ | | _ | | | components, including contaminants and factors on | | | | | | | _ | | | | | _ | | | | | | | |
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| * | | | 4 | | What are the doses related to heavy ions in deep | 7a6 2 | 2 | 7 | - | - | <u>~</u> | <u>F</u> | _ | _ | | | | <u>×</u> | <u> </u> | 7 | | <u>N</u> | | |
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| * | - | | | | What are the particle multiplicities of nuclear | 7b3 2 | 3 | 8 | - | 2 | | <u>×</u> <u>E</u> | _ | | | | | | 2 | 7 | | _ | _ | _ |
| | | | | | interaction products? | | | | | | | | | | - | | | | | | | | , | - |
| * | ç | | | ц | How is a radiation field transformed as a function | 7b4 2 | <u></u> 8 | 8 | _ | 2 | _ | <u>×</u> E | _ | | | | | | 7 | N | _ | _ | <u></u> _ | |
| | <u>_</u> | | | <u> </u> | of depth in different materials? | | | | | | | _ | | | | | | _ | | | | | | |
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| | | | | | shortening, etc.)? | | | | | | | | | | _ | | | | | | | | | |
| | | | | | What are the thresholds required for gravity to | 8la4 | 2 | 9 | <u>-</u> | 7 | <u>-</u> | <u>×</u> E | × | <u>×</u> | × | | _ | , | | <u> </u> | N | | | |
| | | | | | have an effect? | | | | | | | | | | | | | _ | _ | | | | | |
| + | | | | | What are the differences, if any, between species | 8la6 | 2 | 2 | _ | _ | <u>=</u> | Ê | × × | × | × | | | | _ | <u> </u> | <u>N</u> | | | |
| | | | | | and their tissues in their perception and responses | | | | | | | | | | | | | _ | | | | _ | . ** | |
| | | | | | to gravity? | | | | | | | | | | | | | _ | | | | | , | |
| + | | | | | Can plants successfully reproduce through more | 8lb1 | 2 | <u>-</u> | <u>-</u> | _ | _ | <u> </u> | × × | <u>×</u> | <u>×</u> | | | | | | <u> </u> | _ | 7. | |
| | 1 | | | | than one generation in space? | | | | | | | | | | | | | | | | | | , | |
| - | | | | | Is chromosomal integrity and behavior during cell | 81b2 | 2 4 | 9 | Ξ | _ | _ | <u> </u> | × × | × ~ | × | × | | | | <u> </u> | <u></u> | _ | o - | |
| | | | | | division affected in microgravity? | | | | | | | | | | | | | | | | | | | |
| <u>.</u> | | | | | Is cell, tissue, or organ differentiation affected in | 81b3 | 2 | <u>-</u> | <u>-</u> | N | | <u> </u> | <u>×</u> × | <u>×</u> _ | <u>×</u> | | | | <u>-</u> _ | <u> </u> | 2 | _ | | |
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Listed by Category and Criticality Critical Questions

Table 2

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| | 등 | What effect does microgravity have on embryogenesis and the ensuing stages of the life cycle of plants from maturity to flowering and senescence? | Are microgravity-grown tissues and organs competent? | Are the growth rates of higher plants or single cells affected by microgravity? | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered microgravity? | What effect does microgravity have on the synthesis of storage and support polymers? | Are pathways for plant nutrient absorption altered in microgravity? | What are the effects of the space environment long distance transport of water and on transpiration? | How is the effect of gravity (and microgravity) or cells influenced by magnetic fields and radiation? |
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Critical Questions Listed by Category and Criticality

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Critical Questions Listed by Category and Criticality

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| roes in a CELSS? c and terrestrial, vertebrate c and terrestrial, vertebrate c and terrestrial, vertebrate c and terrestrial, vertebrate c and terrestrial, vertebrate igher plants cells ic nutritional requirements for 9b8- 2 2 NR 1 2 1 1 X X X X X X X X X X X X X X X X | CI UZ USI C4 C5 Critical Qu | - 1 | - 1 | Question | Quest# | ပ | | | | ß | 9 | 7 | | | | - | 12 | | | | 9 | 171 | 18 G | iroug | Group w/ other | othe | r Disc | ١ |
| c and terrestrial, vertebrate ligher plants cells cells ic nutritional requirements for 9b8- 2 2 NR 1 2 1 1 X X X his question should consider at his question should consider at ents al requirements of the crew modified diets over time of the macro nutrients (protein, | What is the po | What is the post | What is the po | What is the potential for using the following alternative food sources in a CELSS? | 9a7 | | 2 | - 2 | | 6 | _ | × | 표 | × | | Î | × | T | - | - | 7 | - | 9 | 6, 10, 11 | = | | | T |
| igher plants cells ic nutritional requirements for 9b8- 2 2 NR 1 2 1 1 X X X This question should consider at his question should consider at all requirements of the crew modified diets over time of the macro nutrients (protein, puritient requirements) | Animals (aqui | - Animals | — Animals | Animals (aquatic and terrestrial, vertebrate invertebrate) | | | | | | | | | | | | | | | • | | | | | | | | | |
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| ic nutritional requirements for 9b8- 2 2 NR 1 2 1 1 X X X X X X This question should consider at ents ents al requirements of the crew modified diets over time of the macro nutrients (protein, purples of the macro nutrients (protein, purples of the macro nutrients (protein, purples of the macro nutrients (protein, purples of the macro nutrients (protein, purples of the macro nutrients (protein, | - Tissue-cut - Synthetics | - Tissue-c - Synthetic | - Tissue-c - Synthetic | Tissue-cultured cells Synthetics | | | | | | | | | | | | | - | | | | | | | | | | | |
| ents all requirements of the crew modified diets over time of the macro nutrients (protein, | 4 What are th | What are th | What are th | | | | | ď | 0 | | | | | × | | ^ | | - | , | <u>_</u> | | | C. | 4 | 34 5 67010 | 0 1 | c | |
| ifferents ittoral requirements of the crew ulre modified diets over time of ments of the macro nutrients (protein, ipid) | humans in space? I least the following: | humans in sp least the fol | humans in spleast the follows | This question should consid | | | | | ı | | | | | | | · | | | • | | _ | _ | <u> </u> | , F | j S | | • | |
| titonal requirements of the crew uire modified diets over time of ments of the macro nutrients (protein, ipid) | - Caloric r | - Caloric r | — Caloric r | Caloric requirements | | | _ | | | | | | | _ | | _ | | | | | - | | | | | | | |
| uire modified diets over time of ments of the macro nutrients (protein, ipid) | _ Will the r | _ Will the r | Will the r | Will the nutritional requirements of the crew | | - | | | | | | | | | | | | _ | | | | | | | | | | |
| ments of the macro nutrients (protein, ipid) | change and | change and | change and | change and require modified diets over time of | | | | | | | | | | | | | | | | _ | | | | | | | | |
| of the macro nutrients (protein, | flight | flight | flight | | | | | | | | | | | | | | | _ | | | | | | | | | | |
| of the macro nutrients (protein, ipid) | - Fluid rec | - Fluid rec | - Fluid rec | Fluid requirements | | | | | | | | | | | | | | | | | | | | | | | | |
| ipid) | — Distribu | - Distribu | - Distribu | Distribution of the macro nutrients (protein, | | | - | | | | | | | | | | | | | | | | | | | | | |
| icropitrient requirements | carbohydrate, lipid) | carbohydrate | carbohydrate | e, lipid) | | | | | | | | | | - | | _ | | _ | | | | | _ | | | | | |
| | - Fiber an | | | Fiber and micronutrient requirements | | | | | | | | | | | | | | | | | _ | | | | | | | |

1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge 11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality

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Critical Questions Listed by Category and Criticality

| bility criteria for foods and in 9b9 2 2 NR build they be evaluated? In from toxic substances and respond to diet on a Mars respond to diet on a Mars Interpose a national and the desired requirements? It of options) other menu items It of options) other menu items It of options) other menu items It of options) other menu items It of options) other menu items It of options) other menu items It of options It options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It of options It options It of opt | L | | ŀ | H | Į. | O. Bat# C | Ę | 2 | 3 4 | 9 1 | 9 | | 8 | 6 | 10 | 111 | 2 13 | 2 1 4 | 15 | 16 | 17 | 18 | Group w/ | | other | SSI | <u>6</u> T |
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| what are to acceptability criteria for foods and in 9b9 2 2 NR 1 2 1 1 1 1 2 1 1 1 3. 9. What are the acceptability criteria for floods and form toxic substances and infectious agents — Safety and freedom from toxic substances and infectious agents — How will the crew respond to diet on a Mars — Familiarly countries and articles believed. — Tatastraxture/color/shape — Familiarly countries are prefered. — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Sassoning (diversity of options) — Variety — How can be above nutritional questions apply to CELSS produced roads, used either as a nearly — Options of performance degradation? To what a verter will micro-organisms used in a physico-organism waste processor present an issue of performance degradation? To what averter will are options of sassoning and series? — Variety — What are the storage requirements for potable and goz7 2 2 6 1 2 2 1 X X X X X X I I 2 1 1 3 6 A What are the storage requirements for potable and goz7 2 2 6 1 2 2 1 X X X X X I I 2 1 1 3 6 — Sassity/redurdancy — Converted of microbial film on surfaces — Converted of microbial film on surfaces — Variety | | | ပ္က | 4 0 | Question | | | | T | + | ╀ | ∤≥ | <u> </u> > | > | | ř | - | _ | Ţ | - | - | | 1 | 10 | | | |
| what priority order should they be evaluated? Some orders include: Same priority orders should they be evaluated? Some orders include: Nutrient and attribute balance Taststatus that perver respond to diet on a Mars mission Institution and attribute balance Framiliarity/cultural experience Framiliarity/cultural experience Framiliarity/cultural experience Framiliarity/cultural experience Framiliarity/cultural experience Framiliarity/cultural experience Cooking (time, complexity, etc.) Seasoning (time, complexity, etc.) Cooking (time, complexity, etc.) Seasoning (time, complexity, etc.) Cooking (time, complexity, etc.) Framiliarity/cultural experience apply to get of the acceptable be used or modified to actieve the desired requirements? How can the biomass cardidates be used or modified to actieve the desired requirements a nearly complete diet or as a supplement to stored food? At To what extent will imcro-organisms used in a possible and hygiene extent of sequirements for potable and get or recycling the water required for a Mars mission to acceptable and hygiene water in a CELSS? Consider: Salety/redundancy Complete distribution acceptable and get or cooking film on surfaces At What are the storage requirements for potable and by get or cooking film on surfaces Control of microbial film on surfaces | | - | 4 | - | .⊆ | | 8 | <u>E</u> | | <u>-</u> | | <u> </u> | <u><</u> | < | | <u> </u> | | | | | | | | | | | |
| Some cried include: — Saleay and freedom from toxic substances and infectious agents — How will the crew respond to diet on a Mars — How will the crew respond to diet on a Mars — Have will the crew respond to diet on a Mars — Have will the crew respond to diet on a Mars — Flastelity in preparation methods — Condeng (time, complexity, etc.) — Seasoning (diversity of options) — Compatibility with other menu items — Variety and the longers requirements? — How can the biomass candidates be used or modified to achieve the desired requirements? — How can the biomass candidates be used or modified to achieve the desired requirements? — How can the biomass candidates be used or modified to achieve the desired requirements? — How do the above nutritional questions apply to CELSS produced floods, used either as a nearly complete diet or as a supplement to stored of the achieve the best rechnologies for recycling the physico-chemical waste processor present an issue of performance degradation? What are the best rechnologies for recycling the potable and hygiene levels? What are the best rechnologies for recycling the potable and hygiene levels? What are the coregister in the coordinates are the conditional production of microbial film on surfaces: — Safely/redundancy — Control of microbial film on surfaces: | | | - | | what priority order should they be evaluated? | | | | | | | | | | | | | | | | | | | | | | |
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| infectious agents — Nutrient and attribute balance — Familiarity/cultural experience — Taste/rexture/color/shape — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Familiarity/cultural experience — Cooking (time, complexity, etc.) — How can the binarise candidates be used or modified to achieve the desired requirements? — How can the binarises candidates be used or modified to achieve the desired requirement soft or as a supplement to stored food? To what extent will micro-organisms used in a physico-chemical waste processor present an issue of performance degradation? What are the best technologies for recycling the potable and hygiene levels? What are the storage requirements for potable and gocz? 2 2 6 1 2 1 2 1 1 3 1 1 3 6 1 1 1 3 6 1 1 1 3 1 1 3 6 1 1 1 3 1 1 3 6 1 1 1 3 1 1 1 1 3 1 | | | | | Safety and freedom from toxic substances and | | | | _ | | _ | _ | | | | | | - | | | | _ | | | | | _ |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community Table 2

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| _ | | | | | revitalized air in an operational CELSS? | 9c28 | 8 | e e | 3 | 7 | 2 | = | × | × | _ | | × | | | - | - | 느 | <u>က်</u> | စ | | | |
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| | | | | _ | what technologies will need to be developed for | | | | | | | | | - | | | | | | _ | | | | | | | |
| | _ | | _ | _ | space application? | | | _ | _ | _ | _ | | | _ | _ | | | | | _ | | | | | | | _ |
| | - | 4 | 4 | | What strategies or techniques exist for monitoring | **** | | | | | - | | | _ | | | _ | | _ | | | | | | | | _ |
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| | | _ | _ | | causes of life support system instability? | | | | _ | | | | | | | | | | | | | | ` | | 5 | | |
| _ | _ | _ | | | Consider: | | | | | | _ | | | _ | _ | | | | _ | _ | _ | | | | | | - |
| | | _ | | | - Pests or pathogens (disease) | | _ | | | | | | _ | | | | | | | _ | | _ | | | | | _ |
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| | | _ | | ÷ | - Toxicants produced by humans, by processing | | _ | _ | _ | | | | _ | _ | | _ | | | | | | _ | | | | | _ |
| | | | | = | procedures, or by the plants themselves | | | | | | | | _ | | | | | _ | | | | | | | | | - |
| _ | | _ | | <u>'</u> | - Atmosphere leakage | | | | | | | | _ | _ | _ | | | _ | | | | _ | | | | | _ |
| | | _ | | ÷ | - Perturbations in environmental controls | | | _ | | | | | | | | | | | _ | | | | _ | | | | |
| | | _ | | <u></u> - | - Radiation | | | _ | _ | | | | | | | | | _ | | | | | _ | | | | |
| | | | | <u> </u> | Microgravity | | | | | | | | | | | | | | | | _ | | | | | | |
| | | | | <u> </u> | Unanticipated ecological interactions | | | | | | | | | | | | _ | _ | _ | | | | | | | | |
| | _ | | | <u> </u> | Scheduled or unscheduled system or mission | | | | | _ | _ | _ | _ | | _ | | _ | _ | _ | | | | | | | | |
| | | | | <u> </u> | events | - | _ | _ | _ | _ | | | _ | | | | | _ | _ | | | _ | | | | | - |
| | | - | | | Failure of microbial cultures in algal | | | | | | | | _ | _ | | | | | | | | | | | | | _ |
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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science: Cr=Criticality
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Critical Questions Listed by Category and Criticality

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| 4 What are the requirements for CELSS system design and operation to achieve safe and reliable operation? Address the following: — Subsystem redundancy | | | What are the requirements for Classign and operation to achieve soperation? Address the following—Subsystem redundancy | What are the requirements for Cf design and operation to achieve soperation? Address the followir Subsystem redundancy | SS system e and reliable | 9432 | 0 | ю — | 2 | <u>N</u> | | × | | × | | <u>×</u> | | | <u>-</u> | N | | _ | | | _ | | |
| - Interaction with Chemical - Physical regeneration — System modeling and behavior | Interaction with Chemical - Ptegeneration System modeling and behavior | Interaction with Chemical - Ptegeneration - System modeling and behavior | - Interaction with Chemical - Pt regeneration - System modeling and behavior | Interaction with Chemical - Ptregeneration System modeling and behavior | ıysical | | | | <u> </u> | | | | | | | | | | | | | | | | | | |
| Alternative strategies for system monitoring and control | and control | and control | Alternative strategies for system control Calling of a subsection | Alternative strategies for system and control Exitting of a subsection | em monitoring | | | | | | | | | | | | | | | | | | | | | | |
| Is a CELSS, because it operates within a limited volume and intense dynamics, subject to unknown | | | Is a CELSS, because it operates wi | Is a CELSS, because it operates wi | pa pa | 9433 2 | - | + | + | 2 | - | <u>×</u> | | × | | <u></u> - | × | | | 2 | - | | က် | <u>α</u> | Ξ | | |
| chaotic behavior? What are the thresholds of system size (minimal) and system safety and reliability (maximal), and can these be extended in an integrated, controlled | | | or poorly characterized instabilities chaotic behavior? What are the thresholds of system and system safety and reliability (recan these be extended in an integral | or poorly characterized instabilities chaotic behavior? What are the thresholds of system and system safety and reliability (rean these be extended in an integra | size (minimal) naximal), and ated, controlled | 9d34 | 8 | 8 | - | 8 | 2 | × | | × | | | × | | T | | | | က် | ω | = | | |
| system? How can mathematical models be utilized to aid system design, system simulation, and system | | | system? How can mathematical models be util system design, system simulation, a | system? How can mathematical models be util | ized to aid in nd system | 9435 2 | <u>е</u> | က | - | 8 | 2 | <u>×</u> | | × | | | × | | | N | | | က် | ထ် | - | | |
| operations? What are the power requirements and launch mand volume for an operational CELSS? | | | operations? What are the power requirements and and volume for an operational CELSS | operations? What are the power requirements and and volume for an operational CELSS | l launch mass | 9436 | 8 | Œ | - | N | 2 | | | | | | | | | 2 2 | | | <i>რ</i> (| œ o | = : | | |
| What sensors are required for automation of a CELSS? | | | What sensors are required for autom CELSS? | What sensors are required for autom CELSS? | ation of a | | ო (| 4 (| | | | | × > | ×_> | > | | × × | | <u> </u> | 2 2 | | | , 0 | , , | | | |
| What is the productivity, transpiration, and dry matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | | | What is the productivity, transpiration matter partitioning of plants at less (micro-, 15%, and 38% gravity)? | What is the productivity, transpirati matter partitioning of plants at less (micro-, 15%, and 38% gravity)? | on, and dry than 1xg | 6636 | N (| N (| | | | | | <u> </u> | < > | | < × | | | | | | | 10. | · - | | |
| What is the morphology and reproductive capability of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for space bases? | | | What is the morphology and reprodu of plants at less than 1xg (micro-, 1 gravity)? Will this modify crop self for space bases? | What is the morphology and reprodu of plants at less than 1xg (micro-, 1: gravity)? Will this modify crop self for space bases? | ctive capability 5% and 38% sction criteria | 9640 | N | N | _ | N | _ | | <u> </u> | <u>-</u> | <u> </u> | | . | | | | | | | | | ļ | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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| 3 | <u>8</u> | * 1 | | C2 C3 C4 C5 Critical Question | Quest# | Э | 11 | 2 | 3 4 | 1 | 9 | 1 | Lœ | 0 | 6 | E | 101 | 6 | ; | T | | F | | 1 | | | |
| 4 | | | | What countermeasures can be utilized if productivity or reproduction is significantly decreased? | 9641 | 2 | 2 | 2 | - 2 | | | × | × | × | × | | y | , | + | - 2 | 0 | ` | 0 | 10, 11 | ≩ | other | Disc |
| 4 | | | | What are the effects of the space environment on microbial interactions with space systems and humans? | 9e43 | 8 | - | <u> </u> | - 2 | 0 | | × | × | × | | | × | · · · · · · · · · · · · · · · · · · · | | - 0 | | | | , , | Ξ | | |
| | | | | Can safe and sufficient supplies of food be provided for the trip/stay to/at Mars? Do current expendable systems exist to provide safe and sufficient supplies of food for the Mars mission? | 9f1c | 8 | <u>е</u> | 4 | - 8 | | | × | | × | | | × | · · · · · · · · · · · · · · · · · · · | | | | - | က် | 9 | | | |
| | | | | | 9f5a | ~ | <u>ო</u> | 3 | - 21 | | | × | × | × | | × | | | | - 8 | | | | ဖ | | | |
| | | | | abilities | 9f6a | N | | 8 2 | <u>ო</u> | | ۳- | × | × | × | | | | | | | | | က် | 9 | | | |
| | | | | What are the optimal environmental conditions for sensuring synchronization of circadian rhythms in space, and what are the most appropriate work-rest schedules for ensuring optimal health and performance? | 2a3 | . რ | - CI | 2 | Ν | 8 | _ | × | × | × | | | | | | | | | | | | | |
| | | | | | 2112 | э Э | | 2 | | - 7 | 9 | × | × | × | | | | | | | | | 4 | | | | |
| | | | | sing | 4a5 | 3 | - 24 | m | က | N | - | × | _^_ | × | × | × | | | | | | | 4, | ω | | | |
| ر در | | | | | 7a2 3 | <u></u> | - 2 | | | | Œ | | | | | | | × | 0 | | _ | 2 | | | | | |
| 4 ت | | | | What is the trapped radiation flux as a function of time, magnetic field coordinates and geographical coordinates? | 7a3 3 | <u>ო</u> | rc. | - | | - | 2 | | | | | | | _× | -01 | N | - | - 01 | - | | | | |
| | | ı | | | - | _ | - | - | _ | | - | _ | _ | - | - | - | _ | _ | _ | _ | | _ | _ | | | | _ |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Table 2

| | | | | | | | ł | - | ļ | ł | - | t | r | ŀ | 1 | H | | Ŀ | ľ | 17/6 | واجر | Group w/ other | er Disc | |
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| | } | H | H | H | i | Quest# | <u>1</u> | 8 | e e | 4 | 9 | _ | <u>ဂ</u> ဆ | 10 | 11 | 121 | 3 1 4 | <u> </u> | | <u>- 1</u> | | in dep | | 1 |
| ธ | 8 |) 영 | } | 5 | C1 C2 C3 C4 C5 Critical Question | | 6 | 0 | Ŀ | 2 | Œ | × | | | | | _ | 7 | 2 1 | | _ | | | |
| ÷ | - 2 | | 2 | | What are the cross sections and yields for nuclear | | | | | · | | _ | | | | | | | _ | _ | | | | |
| _ | _ | | | | of HZE particles in ussue and sine | | | | | | | | | | | - | | | | | | | | |
| | | | | _ | materials? | 742 | <u>e</u> | 2 | _ | 2 1 | 2 | × | | | | | | 2 | 2 | _ | _ | | | |
| + | 8 | _ | _ | _ | What are the angular distributions of nuclear | | | | | | | | | | | | _ | | | | | | | |
| | _ | | | | interaction products? | | | | | - | 2 | × | _ | _ | | _ | | 2 | 7 | _ | _ | | | _ |
| • | - | _ | 22 | | What are the optimal ways of calculating the | 765 | <u>ກ</u> | <u>#</u> | | <u>-</u> | <u>-</u> | | | | | _ | | | | _ | | | | _ |
| | | _ | - | | transport of radiation through materials? | | | - | | | _ | : | | | | | | ۰ | - | <u> </u> | | | | |
| , | _ | _ | - 14 | <u> </u> | what are the vields and energy spectra of | 7c2 | <u>э</u> | <u>ო</u> | _ | 2 | _ | <u>×</u> | | | | _ | _ | | 1 | <u>. </u> | | | | |
| _ | | | , | | | + | | | | _ | _ | | _ | _ | _ | _ | _ | _ | _ | | ` | | | _ |
| | | _ | - | | electrons : | (| | , | ٥ | - | 2 | × | _ | | | _ | _ | 8 | <u> </u> | <u>-</u> - | _ | | | |
| + | | 1 | 4 | 2 | How can the wealth of knowledge existing for | ر دع | <u>-</u> | | 1 | | | _ | | _ | | | | | | _ | _ | | | |
| | | _ | | | anergy deposition in gaseous media be extended to | | | | _ | | | _ | | | | _ | _ | | | | _ | | | _ |
| | | | _ | | the liquid phase applicable to most living cells? | | | | | | _ | | _ | | | _ | _ | 9 | | ` | _ | | | _ |
| | | _ | | | and light a second plant and a second plant and | 7.7 | ٠ | 2 | 0 | ٥ | Z C | <u>×</u> | | _ | | | _ | N | - | <u>-</u> - | = | | | _ |
| + | ٥ | | | 2 | How do diffusion, recombination and other | / C4 | | _ | _ | | _ | _ | | | | _ | | | | | _ | | | |
| _ | 1 | | | | interactions of chemical intermediaries alter the | | | | | _ | | _ | | | | | | | | | _ | | | |
| | | | _ | | chomical events at the DNA level? | | | | | | _ | | | | | | _ | | | | _ | | | |
| - | | | _ | | Chemical events at the City 1915. | | 9 | | c | | <u>Z</u> | × | _ | | _ | | | 7 | 7 | <u>-</u> | <u>-</u> | | | |
| - | _ | | | 5 | How is physical energy deposition related to | 60/ | | | | | _ | | _ | | _ | | _ | | | | _ | | | |
| | | | | | biological effect? | | | _ | _ | _ | _ | | | | _ | | _ | 2 | ٥ | <u></u> | 7 | | | |
| _ | | | | | solibora of COO to acidital and a | 741 | က | ა <u>4</u> | <u>-</u> | 2 | <u>~</u> ~ | <u>×</u> | | | | | _ | 1 | _ | | _ | | | |
| <u>-</u> | | | | 2 | What are the probabilities of GCH to produce | | | | | | - | _ | | | | | | | | | | | | |
| | | | | | radiation damage at specific sites on DNA? | | | | | | _ | > | | | | | _ | 2 | 2 | ÷ | - | | | |
| | _ | | | 7 | How are processes like oncogene activation and | 742 | က | 2 4 | <u>N</u> | 7 | <u>-</u> - | <u><</u> | | | | | _ | | | _ | | | | |
| | | | |)_ | oncome suppressor inactivation involved in the | , | | _ | _ | | | | | _ | _ | | _ | | | | _ | | | |
| | _ | | | | carcinopenic effects of GCR radiation? | | | | | | | | | | | | | ٠ | ٥ | _ | - - | | | |
| _ | | | | | modulating | 743 | က | 3 | <u>~</u> | _ | <u>-</u> | <u>×</u> | | | _ | | | <u> </u> | 1 | | | | | |
| _ | 2 | | | Ω | Wildli Illedian and a second for a least | _ | | | | | _ | _ | | _ | _ | _ | | _ | | | | | | |
| | _ | | _ | | radiation damage at the molecular level (legal) | | | _ | | | | _ | | _ | | | _ | _ | | | | | | |
| | | | | | errors in repair, gene amplification, etc.)? | | | | | | _ | | | | | | | 8 | 8 | _ | <u> </u> | _ | | |
| | _ | | | ч | How can molecular mechanisms of radiation | 7d4 | က | <u>8</u> | 4 | | _ | <u><</u> E | | | | | _ | <u> </u> | | | | | | |
| | | | | , | damage be used to understand effects in whole | | | | _ | | | | | | | | | | | | | | | |
| _ | _ | | | | | | _ | | _ | | _ | _ | | _ | _ | _ | | _ | _ | | | | | |
| | | | | | cells? | | _ (| | | _ | | × | _ | _ | | | | 7 | 7 | _ | _ | - | | |
| _ | | | | Ŋ | What is the probability of initiating neoplastic cell | 7.63 | <u>n</u> | <u> </u> | <u>-</u> + | | | - | | | | | | _ | _ | | | | | |
| | | | | | transformation or other steps leading to a | | | | | | | _ | | _ | | | | _ | | | | | | |
| | | | | | cancerous cell? | | 4 | | \dashv | 4 | 1 | \dashv | - | 1 | - |] | 1 | $\left\{ \right.$ | - | | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Table 2

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| دِ ت | | Quest# | ₹ | " | | | | - | | | | | | | | | | | |
| Listed | - | ğ | 794 | 796 | 711 | 794 | 795 | 8Va1 | | | _ | | | | | | | 9a5 | |
| Table 2 | C2 C3 C4 C5 Critical Occasion | HOLLEGO TO THE TANK T | | 5 How can cellular mechanisms of radiation damage be used to understand effects in whole organisms? | | | 5 What is the probability for genetic and developmental detriment incurred as a consequence of radiation exposure in space? | What is the role of gravity in the regulation of circadian rhythms? | What are the effects of the absence of gravity on the generation, expression (period, phase, | circadian rhythms? | - Is it at the synchronizing agent (zeitgeber)? - If not, is it necessary for the action of other | synchronizing agents (light: assercise)? What is the role of arrotation in the | circadian rhythms? | across the phylogenetic scale? Sincle cells to | complex organisms? | the regulation of circadian rhythms? Does this | gravity threshold vary with the complexity of the organism? | and automated procedures should be r planting, growing, and harvesting of | Gob plants? |
| | 18 | \dagger | | | | | | | | | | | | | | | | 4 | |
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Critical Questions Listed by Category and Criticality

| | | | | | | | , | ٠ | | | | İ | Ì | ŀ | ŀ | Į | ŀ | ŀ | ŀ | Γ | l | ١, | | | 1 |
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| 5 | ਲ | ខ | 3 | S | C2 C3 C4 C5 Critical Question | | _ | 1 | Т | Т | ŀ | ļ | T E | + | ┞ | > | | ۲ | 9 | Ŧ | - | 6. | 10, 11 | | |
| - | T | | 4 | | How can molecular genetic technology, including | 9a6 3 | N | _ | <u>ო</u> | <u>ო</u> | _ | × | <u>숙</u> | | | <u>_</u> | _ | | 1 | | | | : | | |
| - | | | | | germplasm screening, be used to develop crop | | | | _ | _ | ; | | | | _ | | | | | | | | | | |
| | | | | | cultivars better fit for CELSS use in space? (for | | | | | | | | | _ | | | | ., | | | | | | | |
| | | | | | example) | | | | | | | | | | | | | | | | | | | | |
| | _ | | | | Improve nutrient quality and bioavailability | | _ | | | | | | | | | | | | | | | | | | |
| _ | | | | | Reduce natural toxicants | | | | | | | | | .— | | | | | 1_ | | | | | | |
| | | | | | Optimize plant architecture | | | | | | _ | ; | | _ | | > | | | | | _ | 6 | 10 | | |
| • | | | 4 | | Can edible foods and/or ingredients be derived | 9513 3 | 7 | _ | 2 | 2 | _ | × | <u>`</u> _ | | | <u> </u> | | _ | _ | | | | | | |
| | | | | | from non-edible plant wastes? | | | | | _ | _ | | | | | | | | | | | | | | |
| | | | | | What are the crop plant-specific limits of this | _ | | | | | | | | | | | | | _ | | _ | | | | |
| | | | | | capability? | | _ | | | | | | | _ | | | _ | | _ | | - | 0 | 1 | | |
| * | | | 4 | | How will non-recyclable materials be minimized in | 9b14 3 | - | 0 | 2 | 2 | <u>-</u> | × | _ | | | _ | | <u> </u> | | | | | | | |
| | | | | | a CELSS program? | | _ | | | | | _ | | | _ | | | | _ | | | 0 | | | |
| | | | | | Vessaga etaamerinae minerali eta eta eta eta eta eta eta eta eta eta | 9617 | 2 | - | _ | 2 | = | × | | _ × | | × | | _ | . <u>N</u> | =_ | _ | <u>,</u> | _ | | |
| _ | | | 4 | | What are the processing requirements mecassary | | | | _ | | | | | | _ | | | | | | | | | | |
| _ | | | | | to convert metabolic wastes into nutrients sultable | | | | | | | | | | | | | | | | _ | | | | |
| | | | | | for plant growth? | | | | | | | > | | | _ | | | | 2 | _ | _ | 3, 6 | | | |
| - | | | 4 | | What will be the limits of the composition of the | 9c18 | 3 8 | | <u> </u> | 7 | <u>-</u> | <u><</u> | | | | | | | | | | | | | |
| | | | | | processed waste streams with regard to the | | | | | | | | | | | _ | | | _ | | _ | _ | | | |
| | | | | | following parameters: | | | | | | | | | _ | | | | | | | | | | | |
| | | | _ | | Organic an inorganic materials | | | | | | | | | _ | _ | | | | | | | | | | |
| | | | | | Potentially toxic materials | | | | | | | | | | | | | _ | | | | | | | |
| | | | | _ | — Water content? | | _ | | - | | | : | | ; | | <u>`</u> > | | | <u>-</u> - | | _ | ٣. | 9 | | |
| <u>-</u> - | | | 4 | | What currently available waste treatment/nutrient | 9c19 | 3 8 | N | =_ | 2 | <u>-</u> - | <u>×</u> _ | | <u> </u> | | <u><</u> | | | | | | | 1 | | |
| | | | | _ | regeneration technologies can be adapted to a | • | | | | | | | | | | | | | | | | | | | |
| _ | | _ | | | CELSS use, and what technologies will need to be | | | | | | | | | | _ | | | | _ | _ | | | | | |
| | _ | | | | developed for space application? (Note question | | | | | | | | | | | | | | | | _ | | | | |
| | _ | _ | | | 16.8) | | | | | | | ; | > | > | | <u>></u> | | | - | | - | 6 | 9 | | |
| | | | 4 | | | 9c22 | დ დ | | | <u>-</u> | | <u> </u> | < | <u> </u> | _ | <u> </u> | | | <u>'</u> | | | | | | |
| - | | | | | compositions of the different waste streams that | | _ | | | | | | | | | | | | | | | | | | |
| | | | | | are to be processed in a CELSS? | | ┨ | \dashv |] | 1 | \dashv | $\frac{1}{2}$ | 4 |] | 1 | ┨ | - | | 1 | \dagger | 1 | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Cniticality
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Page 16 Table 2

| | 1 | Ì | ŀ | t | | ١ | | , | 1 | 1 | 4 | | 6 | 0 | 12 | 131 | 4 | 5 16 | 141 | 18 | Group w/ | other | Disc |
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| 5 | 8 | 8 | <u>2</u> | ह | C2 C3 C4 C5 Critical Question | 3 #18 en 5 | 1 | \top | + | 1 | + | - | 1, | + | } | t | + | ° | - | 6 | 9 | | |
| - | | <u>س</u> | \vdash | Ī | Do automated systems exist to monitor food | 9151 3 | _ | - 2 | 2 | | <u>×</u> _ | | <u>×</u> | . | < | _ | | J | | | | | |
| | | | | | safety/quality for Mars mission? | | | | , | | <u>`</u> | | <u> </u> | <u>×</u> | × | × | | 2 | | - | | | |
| * | <u>,,,</u> | e | 4 | | What provisions must be taken during the course of | 10 2 | 7 | <u>-</u> | =_ | າ | <u><</u> | | <u> </u> | | <u>. </u> | : | | | | _ | | | |
| | | | | | robotic and human exploration to protect the Earth | | | | | | _ | _ | | - | | | | | | | | | |
| | | | | _ | from harm caused by the importation of biological | | | | _ | | | | | | | | | | | | | | |
| | | | _ | | materials from Mars (back contamination)? | | | | | | | _> | > | | | | _ | | - | ' | 4 | | |
| * | 3 | ٠, | 4 | | What environmental conditions of space flight | 293 4 | က | 2 | <u>~</u> | 7 | | <u><_</u> | < | | | | _ | • | | | , | | |
| | | | | | influence temperature regulation? | | | | | | | | > | | | | - | ٥ | ٥ | | 8 | | , |
| | ٥ | က | | | What are the appropriate light wave length cycles | 5c12 4 | က | 3 | <u>n</u> | _ | <u>≺_</u> | <u>< .</u> | <u><</u> | | | | <u></u> | | | | | | |
| | | | | | to maximize vitamin D production? | | | | | | <u> </u> | _ | | | | | - 0 | ٥ | - | | _ | | |
| | | | | 5 | What is the precise energy deposition of heavy | 701, 4 | က | 4 | 7 | | <u> </u> | | | | | | <u> </u> | | | | | | |
| | | | | | ions? | | | _ | | | | | | | | | 0 | ٥ | _ | _ | _ | | |
| + | | | | ĸ | an the radiation effects on cells in culture | 795 4 | 7 | 4 | 2 | | <u>×</u> <u>¥</u> | | _ | | | | | | | | | | |
| | | | |) | related to radiation effects in "normal" cells and | | | | | | _ | | | | | | | | | | | | |
| _ | | | | | tissues? | | | | | | | | > | > | <u>></u> | | | | _ | | 3, 4, 5, | 6, 7 | |
| | * | ٠, | 4 | | How does prolonged space flight affect behavior | 1a9 1 | <u>-</u> | 7 | ა 8 | ო | <u>ო</u> | <u>< </u> | <u> </u> | < | <u><</u> | | | | | | • | | |
| | |) | • | | and group dynamics (including species, sex, and | | _ | | | | | | | | | | _ | _ | | | | | |
| | | | | | age differences)? | | | | | | | | > | _ | <u> </u> | <u>×</u> | | 2 | 2 | _ | 8 | | |
| _ | 2 | (C) | 4 | | What are the factors involved in integrating | 101 | | | <u>-</u> | <u>n</u> | , , | <u>< </u> | <u><</u> | | <u> </u> | <u> </u> | | | | _ | | | |
| | _ | | | | | | | | | | | | | | | | | _ | | | | | |
| | | | | | promote productivity and reliability? What are the | | | | | | | | | | | | | | _ | | | | |
| | | | | | significant issues of control and intervention by | | | | | | | | | | | | | | | | | | |
| _ | | | | _ | human operators, and countermeasures for | | _ | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | <u> </u> | | × | | İ | <u>-</u> | - | _= | က | | |
| | ٠, | er, | 4 | | What are the criteria for evaluating individual and | 1117 | α_ | | <u>-</u> | N. | | _ | < | | <u> </u> | | | · | | | | | |
| | | <u> </u> | | | crew performance and productivity during space | | | | | | | | | | | | | | | | | | |
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| | _ | | | | team performance and what method of detection | | | | | | | _ | | | | | | | | | | | |
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| | | | | | training, crew support) would prove effective? | | \dashv | 4 | 1 | \dashv |] | 1 | ┨ | | 1 | $\left\{ \right.$ |] | 1 | | | | | |

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| | | pact | sory | What are the critical characteristics of leaders that effect reciprocity and productivity of crews? What are the optimal crew command structures for a Mars mission? | What psychological and behavioral characteristics are exclusary? What behavioral and psychometric criteria should be used for selecting candidates for a Mars mission? | What are the protocols for training effective ground teams and space crews in problem solving, enhanced communication, crew coordination, and interpersonal dynamics? | What are the physical and cognisant performance capabilities and requirements of humans in different stages of space flight as a function of mission parameters, e.g. duration, gravity field, physical environment? | ght Id | s of ion, e time |
| | | What are specific countermeasures that impa effectively upon bone and connective tissue structure and function? | Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with long-duration flights result in permanent reflex deficits? | What are the critical characteristics of leader that effect reciprocity and productivity of cre What are the optimal crew command structure a Mars mission? | racte sych idida | What are the protocols for training effective ground teams and space crews in problem so enhanced communication, crew coordination, interpersonal dynamics? | What are the physical and cognisant performan capabilities and requirements of humans in different stages of space flight as a function of mission parameters, e.g. duration, gravity fiel physical environment? | What are the effects of living in the space flight environment on cognitive functions (including attention, memory, information processing and decision-making) and on work capacity? | How do the fundamental behavioral processes of perception and sensation, learning and cognition, and motor skills change in space? What is the tin course of adametion? |
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Critical Questions Listed by Category and Criticality

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| Quest# Cr1 | cedures are needed for analyzing missions 1f1 2 3 | for their demands on human performance (e.g. task analytical techniques and models)? What are the special performance requirements and capabilities and equipment requirements for | extravehicular activity (EVA)? How do circadian rhythm cycles and şleep influence 1f11 2 2 performance and interact with the space environment to affect ability to accomplish mission | goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity? What are the best psychophysiological correlates 1f15 2 2 of effective performance variation in the space environment? In what way do physiological | changes incurred in space affect tash performance? What are the factors that shape individual and team 1g3 motivation and the ability to cope effectively with | environmental stress? Of the various countermeasures available to 3a1 2 5 combat adverse cardiovascular effects on longand short-duration missions, which are most | 3a2 2 1 |

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Table 2

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Critical Questions Listed by Category and Criticality

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| 3 6 | 3 3 | 5 4 | 1 | € | 5c1 | 2 3 | 6 | - | - | 3 | × | × | × | × | <u> </u> | × | | <u>-</u> | - | <u> </u> | | а, 5 | 7 | | | |
| ų_ | | _ | | and connective tissue loss for different areas of | | | | | | _ | | | | | | | _ | | | | | | | | | |
| | | _ | | the body during exposure to microgravity or | | | | | | | | | | | | | | _ | | | | | | | | |
| | | | | simulated microgravity? How is the time course | | | | _ | | | _ | | | | - | | | _ | | | | | | | | |
| | | _ | | of regional tissue loss correlated with changes in | | | | | | | | | | | _ | _ | | _ | | | | | | | | |
| | | | | the tissue stress and strain histories at the same | | | | | | _ | _ | | | | | | | | | | _ | | | | | |
| | | | | site? To changes in regional microcirculation? To | | | | | | | _ | | | | | _ | | | | | | | | | | |
| | | _ | | other regional and systemic factors? | | | | | | | | | | | | | | , | | • | - ` | 7 | 7 | | | |
| 0 | ٠. | 4 | | Which endocrine and nutritional processes are | 5c2 | 2 | ო | <u>-</u> | _ | 1 | <u>×</u> | <u>×</u> _ | × | × | | <u> </u> | | | | - | <u>-</u> | t | | | | |
| _ | | | | required for maintenance of bone and connective | | | | | | | | | | | | | | | | | | | | | | |
| | | | | tissue? How do these processes interact with | | | | | | | | | | | | | _ | | | | | | | | | _ |
| | | | _ | mechanical loading? Are these processes affected | | | | | | | | | | | | _ | | _ | | | | | | | | |
| | | _ | | by space-flight? | | | | | | _ | _ | | | | | _ | _ | | | | | | | | | |
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| 2 | <u>ო</u> | 4 | | Is bone loss reversible in terms of mass, uttra- | 200 | 2 | | | - | <u>'</u> - | _ | _ | <u> </u> | <u> </u> | _ | : | | | | | | | | | | _ |
| | | | | and micro-structural organization, and | | | | | | | - | | | | | | _ | | | | | | | | | |
| | | | | microstructure? To what extent do irreversible | | _ | _ | | | | | _ | | | | | | | | | | | | | | |
| | _ | | | architectural adaptations affect structural | | | | | | | | - | | | | | | _ | | | | | | | | |
| | _ | | | integrity? | | | | | | | - | | | <u> </u> | > | | | • | | _ | _ | 7 | | | | |
| 7 | • | 4 | | How does mechanical stress and changes in stress | 2c8 | 2 | <u>~</u> | _ | - | - | <u>×</u> | <u><_</u> | <u><_</u> | <u><</u> | < | - | | _ | | | _ | | | | | _ |
| | | | | contribute to bone and connective tissue | | _ | | | | | | | | _ | | _ | | | | | | | | | | _ |
| | | _ | | formation? Are stress and/or changes in stress | | | | | | | | | | | | | | | | | | | | | | |
| | | - | | required for continued structural integrity? | | | | | | | | | | ; | > | | | | | _ | + | 7 | | | | |
| ٥ | 2 * 3 | 4 | <u> </u> | What are the critical characteristics or | 5c9 | 2 | 2 | _ | = | _ | ` _ | × × | <u>×</u> | <u><</u> | <u> </u> | | | _ | | | - | | | | | |
| | | | | components of normal daily tissue stress and | | | | | | | _ | _ | | | | | | | | | | | | | | |
| _ | _ | _ | | strain histories that regulate bone and connective | | | | | | | | _ | _ | | | | | _ | | | | | | | | |
| | | _ | | tissue development, maintenance, and adaptation? | | | _ | | | | - | _ | | | | | | | | | | | | | | _ |
| | | - | _ | How are these characteristics affected by | | | | | | | | | | | | | | | | | | | | | | |
| | | | | microgravity? | | | | | | | | | | ; | > | | | | _ | _ | * | 7 | | | | |
| ٥ | * | 4 | _ | How are regional changes in bone and connective | 5c10 | 2 | 2 | _ | | - | e e | <u>×</u> × | <u><</u> | <u><</u> | < | | _ | _ | _ | | | _ | | | | |
| | | | | tissue related to regional changes in muscle | | | | | | | | | | | | | _ | _ | | | | | | | | |
| _ | | | - | tissue? | | | 1 | \dashv | 4 | | ٦ | ┪ | ┥ | 4 | 4 |] | 1 | ┨ | ┨ | 4 |] | | | | ١ | 1 |

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by Category and Criticality Critical Questions Listed

| Colon Colo | | | L | | L | | (2) | | A I CAROLINA | | 2 | 5 | Criticality | <u>></u> | | | | | | | | | | | | |
|--|----|-----|--------------|--------------|-------|---|--------------|---|--------------|--------------|---|---|-------------|-------------|-----|-----|----------|---------------|----|---|--------------|-------------|----------|---------------|-----|------|
| How are neuromuscular activation parterns and forting activity compared to finciduling activity compared to finciduling activity compared to finciduling activity compared to finciduling activity compared to to activity activity activity activity activity activity activity activity activity activity activity activity activity activity activity activity activity activity activity and after the parties at parties activity act | | ਲ | 8 | 2 | ટ | | Questa | 0 | T- | | | 5 | | | ٥ | 5 | [- | | تا | Ľ | Ŀ | Ŀ | ڔٞ | | 1 | Ţ |
| What are the patterns of in-vivo mechanical following resp. strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, strain rate, shorten and some marker data be used degradation? How can bone marker data be used degradation? How can bone marker data be used to investigate and predict regional changes in bone marker data be used to investigate and predict regional changes in bone marker data be used to investigate and predict regional changes in bone marker data be used to investigate and predict regional changes in bone marker data be used to investigate and predict regional changes in bone marker data be used to investigate and predict regional changes in bone marker data because the bonnectanical marker data and becomerative its uses a sensory inputs and coordination of structural and atternation to partial go r1-g after adaptation to partial go r1-g after adaptation of structural and adaptation of motor responses in aftered states of gravity? | | 0 | | 4 | | How are neuromuscular activation patterns and musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to 1-9? | 5c11 | 2 | | | | | | | » × | 2 × | - × | | | - | | | 00 | Grou 7, 3, | 8 g | Sisc |
| What are the bone and connective tissue markers of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used metabolism? What are the optimal countermeasures for motor of muscular outcomes organized for generation of multi-orgaravity? What are the optimal countermeasures for motor (6b3 2 2 1 1 1 2 2 2 X X X X X X X X X X X X | | . 2 | | 4 | | What are the patterns of in-vivo mechanical loading (e.g., tissue strain, stress, strain rate, stress rate)in normal and low-g environments? | 5d1 | | | | | - | | | × | × | | × | | N | | - | | | ω | |
| What key elements of bone and connective tissue structural assembly impact the biomechanical properties? Are there specific load histories that affect the macromolecular assembly of connective tissues? What are specific load histories; What are specific load histories that affect the macromolecular assembly of connective tissues? What are specific load histories? What are sensory inputs and coordination of structural molecules during altered load histories? What are sensory inputs and coordination of muscular outcomes organized for generation of posture and locomotion before, during, and after flight? What are the optimal countermeasures for motor 6b3 2 2 1 1 2 X X X X X X X X X X X X X X X | | · ~ | | 4 | | What are the bone and connective tissue markers of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used to investigate and predict regional changes in bone metabolism? | 543 | | | | | | | | × | × | | | | α | - | | | | | |
| Are there specific load histories that affect the macromolecular assembly of connective tissues? What are specific signal transduction processes relevant to the modulation of structural molecules during attered load histories? What are sensory inputs and coordination of posture and locomotion before, during, and after flight? What are the optimal countermeasures for motor readaptation to partial-g or 1-g after adaptation to microgravity? What adaptive processes modify motor control of motor responses in aftered states of gravity? | Cu | | | | | What key elements of bone and connective tissue structural assembly impact the biomechanical properties? | 546 | | | - | | | | | × | × | | | | | | | <u> </u> | | | |
| 4 What are specific signal transduction processes 5d8 2 2 2 1 1 1 3 X X X X X X X X X X X X X X X X | 2 | | | | | Are there specific load histories that affect the macromolecular assembly of connective tissues? | | | | | | | | ×_ | × | | | - | | | | | | | | |
| Mhat are sensory inputs and coordination of muscular outcomes organized for generation of muscular outcomes organized for generation of motor responses in altered states of generation of motor responses in altered states of gravity? | N | * | | 4 | | duction processes structural molecu | ' | | | - | | | | | × | × | | | | | | | | | | |
| What are the optimal countermeasures for motor (6b3 2 2 1 1 2 2 2 X X X X X X X X X X X X X | ΔI | + | | 4 | | | | | | | | | | _× | | | | | | - | - | | | | | |
| What adaptive processes modify motor control 6b5 2 2 1 1 2 X X X X X X X X X X X X X X X | 8 | | | | | What are the optimal countermeasures for motor readaptation to partial-g or 1-g after adaptation to microgravity? | | | | | | | | × | | | | | | | - | | | | | |
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Table 2

Critical Questions Listed by Category and Criticality

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| | Question | What processes explain the altered perceptions of | joint and body position in microgravity? | countermeasure (physiological system maintenance), will going from 1-g to microgravity cause repeated maladaptions? | What are the joint effects of radiation and microgravity? | How do neoplasms common to chronological aging relate to limitation of cell lifespan and | susceptibility to abnormal growth regulation under altered gravitational fields? | What is the role of gravity in the regulation of the distribution, composition, and pressure of | water/fluids in living systems from cells to complex organisms? How do these changes | influence other homeostatic and regulatory mechanisms? | ls musculoskeletal growth, development, and function compromised during spaceflight and can | they readapt upon return to Earth? The structure and functional systems that should be examined | carefully are: (1) the postural muscles, (2) muscle | spindles, (3) weight/load-bearing bones and joints, (4) intervertebral discs, (5) the architecture of | the connective tissues of the body and (6) | musculoskeletal innervation. | What is the role of fluid redistribution in the | gravity and how does gravity impact the homeostasis of fluid compartments within tissues? |
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Table 2 Page 24

Critical Questions Listed by Category and Criticality

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| | * 0 | | | | What are the human factors issues in teleoperation? | 1d6 | - | | က | _ | - در | <u>×</u> | <u>×</u> | <u>×</u> | | | × | | | N | N | | 4. 5. | · |
| | ۳ * | <u> </u> | _ | | What are the anthropometric requirements for work stations to accommodate individual team members to maximize performance? | 148 | <u>ო</u> | | ო | N | 2 | × | × | × | | | × | | | - | | | - | |
| | 2 | | | | How can artificial intelligence systems be used to support human decision-making in long-duration space flight? | 149 | <u>ო</u> | 2 | က | N | 2 | × | | × | | | × | | | - | N | - | 4 | |
| - 4 | د ع | | | | What are the mission specific design and protocol requirements for telecommunications to optimize crew performance? | 1410 | е 8 | - | ო | - | 2 | × | <u>×</u> | × | | | × | | | _ | N . | | - | |
| | * N | | | | What are the most effective schedules for work, rest and recreation, exercise and sleep for enhancing human performance and adaptation during long-duration exposure to space? | 5 | <u>ო</u> ო | <u>£</u> | m m | N | <u> </u> | × | × | × | | | × | | • | _ | | | 4 | |
| .,, | * | | | | How is workload optimized for various space explorations? | 116 | ъ В | - | ო | - | 2 | <u>×</u> | × | × | | | × | | • | - | - | | | |
| | · N | | | | What minimally intrusive hardware and software capabilities are best suited for obtaining performance data in flight? | 1f10 | <u>გ</u> | _ | 0 | N | - | <u>×</u> | × | × | | | × | | | | _ | - | α | |
| | * 0 | | | | What methods characterize the process of individual and team adaptation to stressors (e.g. isolation, confinement, and risk) inherent in space flight? | 192 | ъ - | <u>£</u> | m m | 0 | - | <u>×</u> | | <u>×</u> | | | × | | <u> </u> | + | د | , | 4 | |
| | 2 * | | | | What are effective protocols for sustaining crews in case of loss of a crew member inflight, or loss of a family member or friend on earth? | 195 | е | 2 Z | В | 2 | е С | × | | × | | | × | | | <u> </u> | | | - | |

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| | Question | What are the effects of the space environment on sleep, sleep cycles, or the generation, expression (period, phase, amplitude and/or waveform), and entrainment of metabolic, endocrine, reproductive, and/or behavioral circadian rhythms? Of these effects, which result from altered gravity and which result from other environmental factors? What are the effects of exercise on circadian rhythms and sleep? What pharmacological and nonpharmacological (e.g. light, exercise) agents can be used to reset the human biological clock? What are the effects of routine administration of | pharmacological agents in space on circadian rhythms and sleep? What roles do age and gender play? Is there a response of the circadian system to the space environment? Does the well documented decrease in red blood cell mass termed "anemia of space flight" represent a normal microgravity-associated adaptive process (self-limiting) or a transient response (self- correcting) to changes brought about by various space-flight-related stimuli (stressors)? |
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Critical Questions Listed by Category and Criticality

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| ო • | | | | What is the most effective way to restore red cell mass during simulated and actual microgravity? Should red cell mass be restored during space flight? Are these acute or chronic changes and are they of sufficient magnitude or duration to pose an unacceptable medical risk and warrant the development of countermeasures (prophylactic or therapeutic)? Formulate mathematical and computer models of tissue adaptation and cellular transient response to altered load histories? | 203 | N | N | ო | М | α | ო | × | × | × | × | | | | | _ | _ | | 4 | , t, | 7, 8 | | | |
| 4 | 4 | | | Is the basal metabolic rate and metabolic efficiency 2e altered during extended space flight? Are there changes in energy metabolism and storage in space, especially in substrate utilization? | 2ē1 | ~ | <u>N</u> | 01 t | - | N | ო | × | × | × | × | | | | <u>, , , , , , , , , , , , , , , , , , , </u> | - | | | _ | ເກົ | _ | | | _ |
| * | | | | What are the optimal noninvasive microanalytical methods and techniques for use during space flight to monitor nutritional status? | 2e2b 3 | <u>e</u> | <u>ო</u> | 0 | N | - | ო | × | × | | | | | | | <u>-</u> | - | | | _ | | | | |
| * Q | | | | What are the mechanisms underlying the negative nitrogen balance and changes in lean body mass incurred during space flight? What are the possible interventions, including dietary afterations in proteins and amino acids? | 203 | 4 | | N | ო | _ | _ | × | × | × | × | | × | | - | | | _ | | ^ | | | | |
| ε. • | | | | Do the effects of space flight require added supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? | 265 | N | N | n | N | Ν | ო | × | × | × | × | | × | | - | - | _ | _ | <u>rī</u> | 4, | 9 | | | |

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Critical Questions Listed by Category and Criticality

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| | ir | How are countermeasures to adverse cardiovascular effects of long- duration space flight affected by changes in fluid distribution? | Are there appropriate animal and/or computer models for studying each functional element of cardiovascular adjustments to microgravity? | Are there changes in cardiac performance and contractile efficiency during long term exposure microgravity? | Is pulmonary function altered in long-duration space flight at rest, exercise, or in a disease state? | What are the physiological similarities and differences of ground- based models of muscle atrophy and fiber transformation and weightlessness-induced muscle atrophy and fiber transformation? How valid are ground-based models for studying the characteristics of space-flight-induced muscle changes? | What are the molecular signals and mechanisms that are responsible for the control of muscle hypertrophy and atrophy, and what are the specific stimuli that are generated by exercise or disuse to signal increased or decreased protein accumulation in muscle cells? | What is the molecular interrelationship between catabolic and synthetic rates of protein metabolism in unloaded muscles? | What is the molecular basis for the effects of unloading on the susceptibility of muscle to in or damage upon resuming normal weight-bearistates? |
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| | Question | | What are histomorphological and architectural 5c7 changes that occur in bone and connective tissue because of space-flight? | Which endocrine-receptor perturbations modulate tissue responsiveness to mechanical stresses? | Which specific models predict bone and connective 5d5 tissue structural transients during altered load environments? | How do changes in mechanical forces and tissue stress (e.g., shear, stress) and/or electrical forces (piezoelectric and tissue streaming potentials) result in mechanisms that are associated with translational alterations in connective tissue structural proteins? | Is cytokine production and response to cytokine by 5d10 osteoblasts and osteoclasts affected by exposure to microgravity? | Are precursor cells of osteoblasts and osteoclasts 5d11 affected by microgravity? | 54 | - |
| | Question | What are the similarities and differences of ground-based models and spaceflight-induced bone and connective tissue loss with respect to biomechanical, histomorphometric, biochemical, and hormonal changes? | | | | | > | | 9 op | еу |
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| | * ~ | - | 4 | | How does gravity interact with other environmental factors to control regulatory physiology and behavior? | 8Vb10 | ო | - | | | 0 | ო | × | × | × | × | × | × | | | - | - | _ | - | | | | |
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| | · N | | | | Do we need artificial gravity countermeasures to protect from physiological deconditioning of a mission to Mars? | 12 1 | ო | - | - 2 | | - | - | × | × | × | × | × | × | | | - | 2 | - | - | , 3, | ဖ | | |
| | * 0 | | | | How should artificial gravity be applied in terms g-load, rotation rate, and intermittent versus continuous exposure? | of 12 2 | n n | <u>හ</u> | ε 8 | - | | | × | × | × | × | × | × | | | - | 8 | - | - | , 3, | ø | | |
| | * ~ | | | | What models can developed to describe the effects of fundamental behavioral stressers on mission performance? | ts 1113 | 4 | <u>~</u> | <u>R</u> | N . | | - | × | | × | | - | × | | | _ | N | - | - | 4 | | | |
| - | . 2 | | 4 | | What are the effects of intermittent and variable gravity fields on circadian rhythms, and how does this affect the use of artificial gravity as a countermeasure to microgravity? | 2a2 is | 4 | <u>۵</u> | <u>е</u> | 0 | 0 | ო | × | × | × | × | × | × | | | +- | _ | _ | - | , 6, | ღ | | |

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Critical Questions Listed by Category and Criticality

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| | 1 | ound-based analogs eme environments o | What are appropriate research models for simulating the effects of the space environment? | What are the effects of non-gravity-related physical-chemical and psychological space-flight-induced stressors on circadian rhythms and sleep? | What are the effects of cephalad fluid shifts on circadian rhythms? | What are the relationships between the stressors associated with space flight; the source, duration and magnitude of the stressor; and decreased immune function? — Are there effective operational procedures or countermeasures to counteract the stressors or their effects? | | | |
| | 1 | ound-based analogs eme environments o | rch models for e space environment? | What are the effects of non-gravity-related physical-chemical and psychological space-flight-induced stressors on circadian rhythms and sleep? | What are the effects of cephalad fluid shifts on circadian rhythms? | What are the relationships between the stressors associated with space flight; the source, duration and magnitude of the stressor; and decreased immune function? — Are there effective operational procedures or countermeasures to counteract the stressors or their effects? | Are there terrestrial (1 g) human, animal and/or computer models that simulate or reproduce the effects of space flight/microgravity with regard to the immune system in space? | What are the effect of changes in cell and nutrient turnover during space flight on nutritional requirements? | What are the effects of prescribed countermeasures on thermoregulation? |
| | 1 | What are the appropriate ground-based analogs studying the effects of extreme environments or human circadian rhythms? | What are appropriate research models for simulating the effects of the space environment? | What are the effects of non-gravity-related physical-chemical and psychological space-flight-induced stressors on circadian rhythms and sleep? | What are the effects of cephalad fluid shifts on circadian rhythms? | What are the relationships between the stressors associated with space flight; the source, duration and magnitude of the stressor; and decreased immune function? — Are there effective operational procedures or countermeasures to counteract the stressors or their effects? | Are there terrestrial (1 g) human, animal and/or computer models that simulate or reproduce the effects of space flight/microgravity with regard to the immune system in space? | What are the effect of changes in cell and nutrient turnover during space flight on nutritional requirements? | What are the effects of prescribed countermeasures on thermoregulation? |
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| Question | Are there appropriate animal and/or computer models for studying each functional element of pulmonary adjustments to microgravity? What is the relationship, if any, between the pulmonary adjustments to space flight and those occurring in Earth-based models such as bedrest, immersion, and head-down titt? | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in response to unloading? | What are the circuitry and signals in the vestibular 6a2a nuclei and brainstem that generate a gravito-inertial frame of reference? What are the roles of the different regions of the cerebellum? | | | |
| Question | | | | | 6b1b | In 6b7 |
| | | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in response to unloading? | What are the circuitry and signals in the vestibular nuclei and brainstem that generate a gravito-inertial frame of reference? What are the roles of the different regions of the cerebellum? | | What is the most appropriate three-dimensional 6b1b model of the angular and linear VOR and of central vestibular processing that will account for alterations in eye movements in microgravity? | What models of sensory-motor transformation can 6b7 be used to predict motor behavior best in attered gravitational states? |

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| | Question | the following cell functions influenced by ad/or affected by microgravity: the n and regulation of genetic information; on; cell differentiation; signal on, including signal-membrane as membrane-effector interactions, and sector linkage; membrane dynamics; lar transport; secretion; alternate regulation; and cell-to-cell sation? The importance of selecting cells ines that can provide interpretable results in precise questions cannot be assized. altered gravitational fields and vectors and matrix connections?? How does into affect these signals under both is and challenge? Representative is would be wounding of dermal fibroblasts tinocytes (or epidermal/dermal wounding differentiation of microvessel endothelial vitro (or growth of the microvasculature particularly following wounding or tumor ion), and application of stress to active | 811b8 |
| | Question | the following cell functions influenced by ad/or affected by microgravity: the n and regulation of genetic information; on; cell differentiation; signal on, including signal-membrane as membrane-effector interactions, and sector linkage; membrane dynamics; lar transport; secretion; alternate regulation; and cell-to-cell sation? The importance of selecting cells ines that can provide interpretable results in precise questions cannot be assized. altered gravitational fields and vectors and matrix connections?? How does into affect these signals under both is and challenge? Representative is would be wounding of dermal fibroblasts tinocytes (or epidermal/dermal wounding differentiation of microvessel endothelial vitro (or growth of the microvasculature particularly following wounding or tumor ion), and application of stress to active | osteoblasts (or bones in vivo). How long can single cells cope with changes in 81lb8 gravitational force without adverse results? Do these effects persist after return to unit gravity? |
| | Question | the following cell functions influenced by ad/or affected by microgravity: the n and regulation of genetic information; on; cell differentiation; signal on, including signal-membrane as membrane-effector interactions, and sector linkage; membrane dynamics; lar transport; secretion; alternate regulation; and cell-to-cell sation? The importance of selecting cells ines that can provide interpretable results in precise questions cannot be assized. altered gravitational fields and vectors and matrix connections?? How does into affect these signals under both is and challenge? Representative is would be wounding of dermal fibroblasts tinocytes (or epidermal/dermal wounding differentiation of microvessel endothelial vitro (or growth of the microvasculature particularly following wounding or tumor ion), and application of stress to active | osteoblasts (or bones in vivo). How long can single cells cope with changes in 81lb8 gravitational force without adverse results? Do these effects persist after return to unit gravity? |
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| H | H | F | ۲ | ı | | | | | | | | | | | | | | | | | | | | | | |
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| 5 | <u> </u> | <u>ડે </u> જ્ | 4 0 | CT CZ C3 C4 C5 Critical Question | Quest# | ပ | - | 2 3 | 4 | 5 | 9 | 7 8 | 6 | 2 | = | 12 | 131 | 4 | 2 | 6 1 7 | 1,2 | _ | | Group w/ | | Г |
| 2 | 2 * 3 | _ | _ | What structural and morphometric alterations will | 0110 | Ŀ | Ť, | T | Ŧ | 1 | T | 1 | 1 | | 1 | • | 7 | F | : | | - 1 | _ | | 5 | - 1 | OI SC |
| | | | | | 0 0 | 4 | _ | - | | Ç¥. | m | <u>×</u> × | <u>×</u> | × | _ | × | | = | _ | _ | Ξ | 'n, | æ, | | | |
| | | ··· | | tissue, and the musculoskeletal systems in long | | | | | | | | _ | | | | | | | | | | | | | | _ |
| | | | | term spaceflight? | | | | | | | | _ | | | | | | | | | | | | | | |
| | | | | esult in altered differentiation | | | | | | | | | | | | | | | _ | | | | | | | |
| | | | | in thousand the state of the state of | | | - | _ | | | | | _ | | | | | | | | | | | | | |
| _ | _ | | | cens, and in changed ussue composition? | | | | | _ | | | _ | | | | | _ | _ | _ | _ | | | | | | _ |
| 2 | * | | | What are the subcellular mechanisms whereby hair | 8IVh1 | 7 | <u>`</u> | , | c | c | | | | _; | ; | | | | _ | | | | | | | _ |
| | | _ | | | · • | | | | _ | | <u>`</u> | <u><</u> < | <u><</u> | <u><</u> | × | × | _ | _ | _ | - | _ | , | ω | | | |
| | _ | | | it and bring about signal transmissions to the | | | | _ | | | | | | | | _ | | _ | | | | | | | | |
| | _ | | _ | the distribution and a spinal manistration of the party o | | _ | _ | | | _ | _ | _ | | | | _ | | | | | | | | | | _ |
| | | | _ | Innuamental mechanism that is true across the | | | | _ | | | | _ | | | | - | | • | | | | | | | | _ |
| | | | | Janimal kingdom? | | | | | | | | | _ | | | | | | _ | | - | | | | | _ |
| 2 | * | _ | | What is the role of growth, or agent the | | | | | | | | | | | | | | | | _ | | | | | | _ |
| <u>-</u> | _ | | _ | Spice of Bravity of Serisory infestions | 8Vb5 | 4 | - | 2 | = | 2 | <u>က</u> | × | × | × | | _ × | _ | _ | _ | • | | ٥ | | | | _ |
| _ | | | _ | (audition, visual, taste, pain)? How do endocrine | | | _ | _ | _ | | | | <u></u> | <u> </u> | | - | | - | | _ | _ | 0 | | | | |
| | | | | neurohumoral, and metabolic mechanisms influence | | | | | | | | | | | | | _ | _ | | | | | | | | - |
| | | _ | | this effect? | | | | | _ | | | | _ | | | | | | | | | | | | | |
| | _ | | | | | | - | _ | _ | | _ | | | | | | | | | | | _ | | | | |
| 7 | <u>ო</u> | | | What role do endocrine and neural systems play in | 2747 | _ | - | | _ | | | | : | : | | | | | | | | | | | | |
| | | | | | ì | | _ | <u> </u> | _ | V | <u>×</u> | <u>×</u> | × | × | | _ × | | _ | <u></u> | = | _ | <u></u> | | | | |
| | - | _ | | diaming medianing anabianing to gravity; | | | - | _ | | | | | | | | _ | - | | | _ | | | | | | |
| 12 | <u>ლ</u> | | _ | What are the systemic, local, cellular, and | 87.12 | | - | _ | _ | ç | <u>`</u> | | > | > | | ; | _ | | | | | | | | | |
| | _ | _ | | subcellular mechanisms involved in adaptation to | ! | | | | | , | | <u><</u> | <_ | <u><</u> | < | <u> </u> | _ | _ | _ | _ | _ | - - | | | | _ |
| _ | | _ | | | | | | | | | | | | | | _ | | _ | | | | | | | | |
| _ | | _ | _ | Secondary and a secondary and a secondary and a secondary and a secondary and a secondary and a secondary as | | _ | | | | | _ | . <u> </u> | | | | _ | | | | | | | | | | |
| | | _ | | associated processes and certito-cell interactions? | | | | _ | | _ | _ | | | | | | | | | | | | | | | _ |
| 2 | <u>ო</u> | | | What are the biochemical pathways responsible for | avia | | | _ | | | | _ | _; | : | | _ | _ | | | _ | | | | | | _ |
| | | | | | 2 | _ | | _ | | Ý | <u><_</u> | <u>×</u> | × | × | | _ × | | - | _ | _ | _ | ^ | | | | _ |
| _ | | | _ | dramatic, sectional, assembly, distribution, and | | _ | _ | _ | | | _ | _ | | | | _ | _ | | _ | | | | | | | _ |
| _ | | | | degradation of structural and functional proteins in | | | | | | _ | | _ | | | | | | | | | | | | | | |
| | | | | muscle in response to altered gravity? | | | | | | | | _ | | | | | - | | | | | | | | | |
| c | | * 0 | | (A) A C C C C C C C C C C C C C C C C C C | | • | | _ | | | _ | | | | | | | | | | | | | | | |
| 4 |) | <u>, </u> | | ine | 2b1 | 1 | LC: | ٥ | c | 0 | × | <u> </u> | <u>></u> | > | <u> </u> | <u> </u> | _ | • | _ | | , | , | | | | _ |
| | _ | _ | | | | | | | 1 | | | | <u><</u> | < | | _ | | _ | | _ | _ | ن. 4 | ŭ, | 6, 7 | | |
| _ | | | | systems (e.g. cardiovasonilar contral | | _ | | | | | | | | | _ | | | | | | | | | | | ••• |
| _ | | | | System immine firsting in the volus | | _ | _ | | | | | _ | | | _ | _ | | | | | | | | | | _ |
| | | | | system, minimine nunction, thermoregulation, | | _ | | | | | _ | | _ | | | | _ | | | | | | | | | |
| | | | | reproductive system, gastrointestinal system, and | | | | | | | | | | | | | | | | | | | | | | _ |
| | | | | | | | | | | | | | | | | _ | | | | | | | | | | |
| - | 1 |] | | | - | | | | | | _ | _ | | | | _ | | _ | | | | | | | | _ |

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Critical Questions Listed by Category and Criticality

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|---|-------------|--------|---|--|--------------|----------|--------------|--------------|--------------|----------|---|---|----|---|------------|---|----------|----|----------|-------------|------------|------|-----------|-----|----------|----------------|-----|
| 5 | C1 C2 C3 C4 | 뚥 | | C5 Critical Question | Quest# | Сr | 1 | 2 3 | 4 | S. | 9 | ^ | 80 | 6 | 9 | Ξ | 2 | 13 | 4 | 2 | - | 7 18 | | d d | `≩ | Group w/ other | SIC |
| + | <u>e</u> | 3 * 4 | 4 | What are the effects of microgravity on renal | 214 | 1 | 1 | 2 2 | 2 | 2 | α | × | × | × | × | × | × | | | _ | | _ | 4 | | | | |
| _ | | | | function, e.g. stone risk? Are the effects | | | | | | _ | | | | | | | | | | | - | | | | | | |
| | | | | differences in filtration, reabsorption, secretion, | | | | | | | | | | | | | | | | | | | | | | | |
| | | - | | and excretion? | _ | | | | | | | | | | | | ; | - | | • | | | (| | | | |
| | က | * | | | 3a3 | - | - | ا | - | ო | ო | × | × | × | <u>×</u> _ | | × | _ | | | | | ٥ | | | | |
| | | | | extravehicular activity (EVA) at various levels of | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | gravity (e.g., microgravity, planetary surface | | | | - | | | | | | | | | | | | | | | | | | | |
| | _ | | | exploration)? What factors influence the | | | | | | | | | | | | | | - | | | | _ | | | | | |
| | | | | occurrence, magnitude, and sequence of titlese | | | | | - | | | | | | | | | | _ | | _ | | | | | | |
| | | | | responses? | | | | | | | | | _ | | | | | _ | | | | : | _ | | 1 | ď | |
| _ | n | * | | Following long-term space flight, are there delayed | 3a12 | - | Z) | S. | 3 | က | က | × | | × | × | | × | | | <u></u> | | _ | <u>က်</u> | 4 | ູ່ ດໍ | α | |
| | _ | | | or persistent consequences, either beneficial or | | | | | | | | | | | | | | | _ | _ | | _ | | | | | |
| | | | | harmful? As a corollary, are there appropriate | | | | | | _ | | | | | | | | _ | | | | | | | | | |
| | | | | rehabilitative measures that should be applied both | | | | | | | | | | | | | | _ | _ | | | _ | | | | | |
| | | | | in the near-term (hours to days) and long-term | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | (months to years) after flight? | | | | | - | | | | | | | | | | | | | | | | | | |
| | ო | * | | Which pulmonary life support procedures should be | 3 b 3 | - | 8 | - | 2 | _ | _ | × | × | × | | | × | | <u> </u> | <u>-</u> | | | ω | | | | |
| | | | | used for effective protection or resuscitation of | | | | | | | | | | | | | | | _ | | | | | | | | |
| | | | | crewmembers in the event of loss of pressure in | | | | - | | _ | | | | _ | | | | | | | | | _ | | | | |
| | | - | | the EVA suit or cabin, and for cardiopulmonary | | | | _ | | | | | | | | | | | | | _ | - | _ | | | | |
| | | | | resuscitation and general anesthesia? | | | | | | | | | | | | | ; | | | | | | | | | | |
| _ | 2 | ٠ د | _ | What procedures and approaches prevent | 4c2 | <u>-</u> | က | က | - 2 | ~ | _ | × | | × | | | × | | | _ | | | 0 | | | | |
| | | | | decompression sickness or minimize crew risk? | | | | | | | | | | | | | | | - | | | 1 | | | | | |
| | 2 | ÷ 6 | | Treatment of medical problems of spacecraft inner | 4c3 | _ | က | e | - 2 | 2 | _ | × | × | × | | _ | × | | | | _ | _ | _ م | | | | |
| | | | | temperature, and adverse effects of the gaseous | | | | | | | | | _ | | | | | | | | | | | | | | |
| | | | | environment? | | | | | | | | | | | | | | | | | | | | | | | |
| _ | (-) | ÷ ص | | What are the risks for bubble formation and clinical | 4c9 | _ | က | 4 | 1 | | က | × | × | × | | | <u>×</u> | | | | <u>-</u> - | | xo | ٥ | | | |
| | | | | decompression sickness associated with various | | | | | | | | | | | | | | | | | | | _ | | | | |
| | | | _ | pre-EVA denitrogenation/decompression schedules | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | and exercise? | | _ | | | ┪ | \dashv | ┥ | 4 | 4 | 4 | 4 | 4 | | | ٦ | 1 | 1 | 1 | 1 | | | | |

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Listed by Category and Criticality Critical Questions

Table

| C2 C3 C4 C5 Critical | 24 05 | 55 | - | Question | 0.00 | | Ţ | ٦ | | | 4 | 1 | Ŀ | [| | Ţ, | 7 | Ţ | Ţ | Ī | Ī | h | ħ | | | Г |
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| | | | | 1 | *1000 | - | 7 | | 7 | 2 | ۱ | 4 | <u>ه</u> | S | 2 | =1 | 121 | <u>و</u> | 2 | 2 | 9 | 7 | ∞ | Group w/ other | other Disc | ပ္က |
| tendon, and the strop tendon, and the susceptible to normal weight | | Loes the atrop tendon, and the susceptible to normal weight | Loes the atropted tendon, and the susceptible to normal weight | Loes the atrophy from unloading make muscle, tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | 5a9 | T | N N | <u>လ</u> | <u></u> | | ო | × | × | × | × | | × | | | | | _ | | | | |
| 3 • 4 What potential development of metastatic call formation? | 1 | What potential development of metastatic call formation? | What potential development metastatic call formation? | What potential risks does bone loss present to the development of bone fractures, hypercalcemia, metastatic calcification, and renal stone formation? | 5c4 | + | <u>ო</u> | г | <u>N</u> | | ო | × | × | × | × | | × | | | | | | 7, | 4 | | |
| * 5 How are risks space radiatio | | | How are risks space radiatio | How are risks associated with acute exposure to space radiation to be managed medically? | 7g6 | _ | 4 | | | က | £ | × | | × | _ | | × | | | | | | თ | | | |
| What is the n in effect of v | What is the n | What is the n in effect of v | What is the n in effect of v | What is the nature of space flight-induced changes in effect of vasoactive drugs? | 2614 | ~ | <u>ო</u> ო | <u>~</u> | - | 8 | - | × | × | × | × | <u>×</u> | | | _ | | | | 4, | 9 | | |
| What is the pharmocokin | What is the pharmocokin | What is the pharmocoking | What is the pharmocoking | | 2015 | 8 | <u>ဗ</u> | ~ | | N | - | × | × | × | × | <u>×</u> | | | | - | | - | 4, | ဖ | | |
| * 4 What are the the themoregula | | What are the themoregula | What are the the the the the the the the the th | What are the effects of space flight and/or EVA on thermoregulation processes and heat exchange? | 2g1 | 7 | 2 | 2 | <u>~</u> | | | × | × | × | × | | | | | | _=_ | | 4, | φ | | |
| There is an associated we the specific | There is an associated we the specific | There is an associated we the specific | There is an associated we the specific | | 3a6 | N | <u>ဗ</u> | - | ო | | N | × . | × | × | | <u>×</u> | | | - | | | | 2 | | | |
| Does the extent of ada orthostatic tolerance? | Does the ex | Does the ex orthostatic | Does the ex orthostatic | | 3a9 | α (i) | က | | <u>£</u> | ~ | ო | × | × | × | × | _×_ | | | | | | | , 5 | 4 | | |
| Since micro flows to son functional co | Since micro flows to son functional co | Since micro flows to son functional co | Since micro flows to son functional co | Since microgravity afters blood pressures and flows to some tissues, what are the structural and functional consequences in these various tissues. | 3a13 | 0 | 2 | | | ო | n | × | × | × | × | × | | | | | | | 5, | 4 | | |
| and organ s What is the | | and organ s What is the the human in | and organ s What is the the human in | n (9 | 4b3 | <u>9</u> | <u></u> | ო | | <u>N</u> | | × | × | × | | × | | | - | | - | | 4 | | | |
| How comple repair in m | How comple repair in m | How comple repair in m | How comple repair in m | | 5a10 2 | 21 | <u>ო</u> | <u> </u> | | | က | × | × | × | × | <u>×</u> | | | | | | | ^ | | | |
| | | | | | | 1 | $\frac{1}{2}$ | 1 | - | _ | | | | | - | - | _ | - | _ | _ | _ | - | _ | | | _ |

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Critical Questions Listed by Category and Criticality

Table 2

| C1 C2 C3 C4 C5 Critical | Question | Quest# | C r | 1 | 2 3 | 4 | 2 | 9 | 4 | 8 | 9 | 0 | = | 2 | 9 | 4 | 5 16 | 17 | 18 | | Group w/ other Disc | othe | اة |
|-------------------------|--|--------|-----|----------|-----|---|---|---|---|---|---|---|---|---|---|---|------|----|----|-------|---------------------|------|----|
| '₹ | How will the reproductive status of premenopausal 8 | 81111 | 2 1 | <u> </u> | - | - | 7 | ၈ | × | | ÷ | × | | | | _ | | _ | | 3, 4, | 7 | | |
| 0 | female crewmembers be managed to minimize the | | | | | | | | | | | | | | | | | | | | | | |
| • | risk of pregnancy, osteoporosis, and hemorrhage | | | | | | | | | | | | _ | | | | | | | | | | |
| _ | from ruptured follicles during ovulation? What is | | | | | | | | | | | | | | - | | | | | | | | |
| _ | the role of gravity in developmental biology? | | | _ | | | | | | | | - | | | | _ | | _ | | | | | |
| | Does the developmental ontogeny of animals | • | | | | | | | | | | | | | | | | | | | | | |
| _ | raised through more than one life cycle under a | | | | | | | | | | | | | _ | | | _ | | | | | | |
| | changed gravity field differ from the 1-g classical | | | | | | | | | | _ | | | _ | _ | - | | | | | | | |
| | pattern? Does this altered pattern reside in the | | | | | | | | | | | | | | | | | | | | | | |
| | genome, or is it relayed from hormonal and | | _ | _ | _ | | | | | | | | | _ | | | | | | | | | |
| | stromal interactions? | | | - | | | | | | | | | | | | | | | | | | | |
| • | Are there critical windows of susceptibility for | | | | | | | | | | • | | | | | | | | | | | | |
| | developmental processes, or is development | | | | | _ | | | | | | | _ | | | | | | | | | | |
| - | affected in a gradient? | | | | | | | | | | | | _ | | | | | | | | | | |
| | - If gravity-related effects exist, can they be | | | | | | | | | | | | | | | | | | | | | | |
| | reversed in the short- or long-term? | | | | | | | | | | _ | | | | _ | - | | | | | | | |
| - | - What will be the result of gravity-induced | | | | | | _ | | | | | | | | | _ | | | | | | | |
| | dys-synchrony (temporal or hormonal) during | | | | | | | | | | | | | | | | | | | | | | |
| _ | development? | | | | | | _ | | | | | | | | - | _ | _ | | | | | | |

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| | Quest# | 4 18 | 8Vb9 | £ 4 6 |
| | ۴ | | | 2d3 2d9 |
| | | What are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can altered gravities affect fertilization, and do these results indicate more general mechanisms of membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on | the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? How does gravity affect compensatory mechanisms (e.g. endocrine, organ, circulatory, regenerative processes)? What is the interaction with growth stages? What is gravity's effect on wound healing? | засе |
| | | What are the effects on the male and female gerrcells of protracted, chronic, low dose exposure space radiation outside the Van Allen belts? Whevents in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can altered gravities affect fertilization, and these results indicate more general mechanisms membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embrycan. What are the results of altered gravity fields. | the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? How does gravity affect compensatory mechanisms (e.g. endocrine, organ, circulatory, regenerative processes)? What is the interaction with growth stages? What is gravity's effect on wound healing? | 11.7 Sp. 17.7 |
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Critical Questions Listed by Category and Criticality

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| C2 C3 C4 C5 Critical Question | = | distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space | Does space flight alter gastrointestinal function, including the absorption of essential nutrients and the function of each form? What are the effects | of space flight on liver function? Are the effects progressive? Are they reversible? | What are the time course and magnitude of fluid | shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during | return to 1 g after flight? | • | diuresis, natriuresis, and kaliuresis resulting from | exposure to hypogravity: | In the environment of microgravity, does the | by aerosol particles in the lung? In the spacecraft | environment, what are the aerosol concentrations, | particle size profiles, and bacterial | contaminations? Do these factors constitute a | health hazard? | 5 What is the role of gravity on thirst and feeding | behaviors (appetite, taste preference, and | What are the machanisms inducing the south loss of | 2 |
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Listed by Category and Criticality Critical Questions

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| <u>`</u> | Question Quest# C | For the well documented changes in calcium 3a20 metabolism associated with space flight, what are the direct and indirect consequences for electrical, mechanical, and vascular events in the heart? | Does space flight affect pulmonary aging or disease 3b5 processes commonly found in adults in a 1-g environment? How is subclinical pulmonary pathology (e.g., incipient bronchospasm, early emphysema) affected by space flight? Do these same questions apply to healing processes in the | In terms of the fluxes of matter and energy that 11b1 3 maintain disequilibrium conditions, what universal metrics can be developed for assessing the potential of different microenvironments to support the origin and evolution of life? | What bounds do the energetics and dynamics of accretion and core formation place on the time when surface temperatures became suitable for the occurrence of liquid water? | What fluxes of intact organic compounds could have 11b3 3 been supplied to the Earth's atmosphere and surface waters by accretion of cometary or carbonaceous chondritic material? | What geological settings were conducive to the 11b4 3 origin of life? | What were the earliest products of the interaction 11b5 3 of liquid water or atmospheric gasses or both with crustal rocks? | What minerals were available as potential chemical 11b6 3 catalysts in the boundary regions? |
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Critical Questions Listed by Category and Criticality

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| | † | 4 | What photochemical processes occurred in the | 1168 | 3 | 2 | ٠ | - | - | - | × | | × | | | | × | - 2 | | | _ | 13, | 3, 14 | ₩. | |
| | | | atmosphere, at the interfaces of the atmosphere with oceans and land, and in surface waters? | - | | | | | | | | | | | | | | | | | · | , | | | |
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| | | | nitrogen fixation by photochemical or other processes? | | | | | | | | | | | | | | - | | | | | | | | - |
| | | 4 | ne nature of the earliest geochemical | 11510 | <u>د</u> | 3 | ٥. | | ო | _ | × | | | | | | × | 8 | <u> </u> | _ | _ | <u> </u> | 13, 1 | 4 | |
| | | | cycles of the biogenic elements and over what time | | | | | | | | | | | | | | | | | | | | | | |
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| | | | active boundary regions over time? | | | | | | | | _; | | | | | | _ | | _ | _ | | _ | 12 | 74 | |
| | _ | 4 | In what ways was Earth unique, relative to Mars | 11b13 | en en | | <u>~</u> | _ | ო_ | _ | <u>×</u> | | | | | | <u> </u> | <u> </u> | | _ | _ | <u> </u> | | t | |
| | | | and Venus, in its ability to evolve and maintain its | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | hydrosphere? | | | | | | | - | | | | | | ; | — ; | | | | | _ | | • | |
| | <u>-</u> - | • | To what extent has chemical evolution of the | 11b14 | ن د | <u>ფ</u> | <u>ن</u> | - | _ | _ | × | | ×_ | | | × | × | | N | | | | <u>.</u> | * | |
| | | | biogenic elements and compounds occurred on | | | | | | - | | | | | | | | | | | | | | | | |
| | | | planets other than Earth, and why did it take | | | _ | | | | | | | | | | | | | | _ | | _ | | | |
| | | | different courses? | | | | _ | | | | | | | | | , | | | | | | | | | |
| | | . 4 | What evidence is there for the presence of biogenic 11b15 | | ر س | 4 | <u>د.</u> | <u>-</u> | _ | _ | × | | × | | | × | × | | Z | <u>-</u> - | _ | _ | ກ໌ ກໍ | 4 | |
| | | | compounds of abiotic origin in planetary materials, | <u> </u> | | | | | | | | | | | | | | | | | | | | | |
| | | | including Earth? | | | | | | | | | | | | | | -; | | | | <u>`</u> | <u> </u> | | * | |
| | | 4 4 | How did carbon chemistry lead to self-replicating | 11616 | ი | е — | <u>د.</u> | - | က | _ | <u>×</u> _ | | | | | | × | | | - | | | | <u>+</u> | |
| | *** | | systems? | | | | | | | | | | | | | | ; | | | | | | | 3 | |
| | | 4 | In what ways have physical changes in the | 1161 | က | <u>ر.</u> | <u>ن</u> خ | _ | က | <u>-</u> | × | | | | | | × | <u> </u> | N | | - - | | ر ان | 4 | _ |
| | | | planetary surface environment influenced both the | | | - | | | | | | | | | | | | - | | | | | | | |
| | | | rate and the direction of early microbial evolution? | | | | | _ | | | | | | | | | | | | | | | | • | |
| | | 4 | What is a geological time scale for major events in | 11c2 | ო | <u>ლ</u> | <u>ن</u> | _ | _ | - | <u>×</u> | | | | | | × | | N | _ | | | <u>.</u> | 4 | |
| | | | biological evolution? | | | | | | _ | | | | | | | | | | | | - | | | 3 | |
| | | 4 | How have the evolving biota, in turn, modified and | 11c3 | ო | n n | <u>ن</u> ن | ~ | ၈ | | × | | | | | | × | | N | | _ | | <u>,</u> | <u> </u> | |
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Table 2

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions Listed by Category and Criticality

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| | | | 4 | ļ | Look for extant life (does it exist?) on Mars — Microenvironments exist? — Life there? | 11d19 3 | 4 | 8 | ٥. | - | - | F | × | | | | | × | | 2 | | - | | 1 3, | 4 | |
| | | | 4 | | What are the acute and long-term effects of the space environment on sleep architecture, quantity, and quality? | 1114 | - | Q | ო | α | - | N | × | <u>^ </u> | × | | <u>×</u> | | | - | Ψ | - | | 4 | | |
| | α | က | * | | What are the mechanisms regulating thirst and electrolyte appetite during space flight? | 2f9 4 | 7 | - | N | N | N. | m | × | ^ | <u>×</u> × | ~ | × | ~ | | | - | | | | | |
| | | | | | What, if any, are the cardiovascular morphological changes associated with acute or long-term exposure to space flight (e.g., effects of mirronavity radiation or environmental hazards | 3a15 4 | ო | ro. | e | α | - | , 1 | × | × | | | | | | 7 | <u> </u> | | - | | | |
| | | | | | | | | | | | | | - | | | | | | | | | | | | | |
| | | | 4 | | Does atrophy of smooth muscle in the leg vasculature occur during long-term space flight? How are vascular endothelial structure and function altered by such exposure and what are the consequences? | 3a16 4 | ო | ഗ | e e | α | <u>-</u> | - | × | × | | | | | | α | | | | | | |
| | | | 4 | | What is the nature of the interplay between hemodynamic and electrophysiological responses to space flight and how much of this is reflex mediated? | 3a17 4 | ო | ഹ | ო | N | - | - _ | × | × | | | | | | α | - | - | _ | | | |
| | | | 4 | • | What are the correlations between the physiological responses demonstrated in the various microgravity study environments (e.g., KC-135, COSMOS, RAHF) that are available? | 3a18 4 | 4 | φ | ო | က | - | 2 | | | | | | | | N | <u>-</u> | | - | | | |
| | | | 4 | | What is the nature of microgravity-associated changes in the autoregulatory mechanisms of arterioles, venules, and lymphatics? What role do these changes play in the adaptation to | 3a24 4 | | 0 | ო | - | - | 0 | | × | × | × | | | | α | <u>-</u> | | | | | |
| | | | | | microgravity and return to normal gravity? | | | _ | | | | | | | \dashv | | ᅱ | - | ᅱ | ᅱ | ┪ | ᅦ | \dashv | \dashv | | |

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Critical Questions Listed by Category and Criticality

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| | Question Quest# C | the structure-function relationships of 6d1 4 | 66 8 | , 8lla2 | perturbation? Is the cytoskeleton organization of cells disturbed by gravity perturbation? How does the cell's cytoskeleton, outer membrane and nuclear envelope/nuclear matrix react to altered | gravity, as a three-dimensional continuum of perception and structural integrity? | If single cells are too small to detect changes in the 81la3 gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? | If multicellular systems are necessary for gravity 811a6 sensing, how is this effected? What cellular structures and processes that extend across several cells might be involved? What aspects of | cell-cell communication are affected? Would the requirements for cellular interaction/assembly increase sensitivity to indirect or environmentally mediated effects (e.g., reduction of cell-cell and | cell- surface contact by dispersion of cells in microgravity)? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science: Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Critical Questions Listed by Category and Criticality

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| 5 | ଧ | ខ | C1 C2 C3 C4 C5 | 의 | Critical Question | Quest# | Cr | - | 2 | 3 4 | 4 5 | 9 : | - | - | 6 | 10 | E | 12 | 13 | 14 | 151 | 16 | 12 | 18 | ŏ | ٥ | Group w/ other | Disc |
| | 0 | ო | 4 | • | What are the mechanisms involved in the transduction of the stimulus of altered gravitational force to a cellular response? By | 81lb1 | 4 | - | - | - | - 2 | <u>ო</u> | × | × | × | | × | | - | | 1_ | | _ | 1_ | 4, 5, | . 7' | 8, | |
| | | | | | what pathways is the perception of attered gravity relayed intracellularly and/or extracellularly? | | | | | | | | | | | | _ | | | | | | | | | | | · |
| | N | ၉ | 4 | • | How does gravity affect organogenesis and the development of anatomical structures? | 81117 | 4 | <u>_</u> | <u> </u> | | | ო | × | × | × | × | × | × | | | _ | | | | , 8, | 'n | | |
| | | | | | Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular, | | | | | | | | | | | | | | | | · | | | | | | | |
| | | | | | musculoskeletal) of young and adult animals similarly sensitive to this stimulus in ontogeny? | | | | | | | | | | | | | | | | | | | | | | | - |
| | | | | ro. | What are the optimal conditions for synchronizing the circadian rhythms of mission control passons | 2a5 | 4 | | | | | | × | × | × | | | | | | <u> </u> | | - | | | | | |
| | | | | | to the mission schedules? How is performance of | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | mission personnel affected by their various work- rest schedules? | | | | | - | | | _ | | | | | | | | | | | | | | | |
| | | | 4 | ່ເດ | 5 What are the long-term effects of the space | 2a10 | 4 | | | | | | _× | × | _ <u>×</u> | × | | × | | ~ | | | | | | | | |
| _ | | | | | environment on the interaction between the circadian system and ultradian and infradian | | | | | | | | | | | | | | | | | | | | | | | _ |
| | | _ | | | rhythms, especially reproductive systems? | | | | | | | | | | | | | | _ | | | | | _ | | | | |
| | | <u> </u> | 4 | 'n | 5 What are the hypothalamic-pituitary-adrenal and opioid system responses to normal space-flight | 2b2 | 4 | | | | | | <u>×</u> | × | × | | | × | | | | | | | | | | |
| | | | | | events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, and | | | | | | | | | | | | | | | | | | | | | | | |
| | | | - | | environmental stimuli? | | | | _ | | | | | | | | | | | _ | | _ | | | | | | |
| | | ` | 4 72 | ب د | 5 * What are the acute and chronic effects of space flight on endocrine system homeostasis and | 2b3 | 4 | | | | | | × | × | × | × | | × | | | | | | | | | | |
| | | | | | responsiveness? | | | | | | _ | | | | | | | | | | | | | | | | | |
| 7 | | 4 | 4 | 5 | 5 'How does space flight affect the pharmacodynamics of hormone action the | 2b4 | 4 | | | | | - | × | × | × | | | | | _ | | | | 4, | ω, | | | |
| _ | | | | | permeability of the blood-brain barrier, and the | | | | | | | | | | | | | | | - | | | | | | | | |
| ┥ | \dashv | \dashv | \dashv | 7 | action and metabolism of normones? | | | | | | | | | | | | | _ | | | | | _ | | | | | |

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Critical Questions Listed by Category and Criticality

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|---|---|---|---|----------|--|---------|-----|----------|--------|----|----------|---|---------------|---------------|-------------|-----|---|---|----------|------|----------|--------------|----------------|------|-------|-----|
| ຽ | გ | ප | 8 | \aleph | C1 C2 C3 C4 C5 Critical Question | uest# C | 1 2 | <u>د</u> | 4 | ç. | و | | <u>ာ</u> | 4 | - | 7 - | 2 | 4 | <u>^</u> | • | <u> </u> | | Group w/ ourer | | | 2 |
| | | | 4 | 'n | 5 How do altered biological rhythms associated with 2b5 long-term space flight affect hormone secretion and function and vice versa? | 4 | | · | | | | × | × | <u>×</u> | | × | | | | - | - | _ | | | | |
| | N | | | ro. | 5 * What are the time courses and magnitudes of changes in the erythropoietic system during space flight? | 4 | | | | | | | <u>×</u> × | × | | × | | | + | - | _ | - | | | | |
| | N | | | ro | 5 * What is the relationship between altered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | 7 | | | - | | | × | <u>×</u> × | <u>×</u> | × | | | | - | - | - | - | | | | |
| | N | | 4 | ιΩ | 5 * What are the major factors and associated another mechanisms that contribute to the "anemia of space flight"? | A 4 | | | | | | | × | × | | | | | - | - | - | - | | | | |
| | | | | | What controls the alterations in red cell production or survival? Does the loss of red cell mass result from an | - | | | ****** | | | | 1 | | | | | | | | | | | | | |
| | | | | | impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? | | | | | | | | | | | | | | | | | | | | | |
| | | | 4 | Ŋ | 5 * Is the "anemia of spaceflight" related to a direct 2c7 effect of microgravity or other space-flight-induced stressors on bone marrow structure, function, or cellular interaction? | 4 | | | | | | | × | <u>×</u> × | | | | | | · | T- | - | | | | |
| | 0 | | | v | 5 * Are periods of recovery from "anemia of space 108 flight" physiologically analogous to those in subjects who donate blood or otherwise undergo phiebotomy, and can this recovery be accelerated? | 8 | | | | | | × | × | × | | | | | | _ | - | - | | | | |

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Critical Questions by Category and Criticality Listed

Table 2

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Critical Questions Listed by Category and Criticality

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| 5 + Do | 5 * Do | 5 * Do | <u> </u> | 5 * Do any of the changes in the immune system predispose crewmembers either during or after flight to infectious diseases, allergies, or delays in proposed from disease. | 2d8 | 4 | | | | | | × | × | × | | × | | | | - | - | . | | | | |
| 4 .v .A # 5 9 9 | | . A π 5 g g | 5 4 5 5 <u>7</u> 2 | Are there other in-vitro/biochemical assays that reliably predict or reflect decreases in immune function and if added to the current battery of postflight tests, would give a more complete picture of factors affecting immune function? | 2d10 | 4 | | | | | | × | | <u> </u> | | | | | N | * | - | - | | | | |
| .v. • | ν • • • • • • • • • • • • • • • • • • • | ი • • გდ <u>ი</u> | r ≥ a Ω o | 5 • What are the energy requirements of EVA? What are the effects of deconditioning, EVA, and countermeasures on nutritional requirements and body composition during space flight? | 2e6 | 4 | | | | | | × | × | × | | × | | | - | | - | 8 | | | | |
| 4 5 * A | | * 5 | ₹ 8 | 5 * Are there valid ground models and analogs for the study of the effects of space flight on nutrition? | 2e7 | 4 | | | | | | × | × | × | - | <u>×</u> _ | | | 0 | | 8 | - | | | | |
| * | * | * * | > 0 0 m.= m t | What is the optimal presentation, nutritional and caloric formulation of the diet for maintaining crew health and performance in space flight? What are the behavioral and performance responses of individuals to particular food constituents during space flight? Are there changes in dietary | 2 6 9 | 4 | | | | | | × | × | × | | <u>×</u> | | | - | - | - | ₩ | | | | |
| | | | | preference: Is there a change with respect to "food allergies" or other abnormal reactions to foodstuffs? | 2e10 | 4 | | | | | | × | × | × | | <u>×</u> | | | | _ | - | - | | | | |
| 5 | ro * | * | W | What are the effects of space-flight-related factors, (e.g. bone demineralization and light spectrum) on nutritional requirements? | 2012 | 4 | | | | | | × | × | × | × | × | ~ | | - | <u>-</u> | | - | | | | |
| 2 * | * 0 | * 2 | | 5 • What changes in carbohydrate/lipid metabolism occur during space flight? Are they modified by dietary intake? | 2613 | 4 | | | | | | × ' | × | × | × | <u> </u> | $\overline{}$ | | | - | - | - | | | | |

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| C1 C2 C3 C4 C5 Critical Question | 5 What are the relationships of fluid and electrolyte responses to space flight on sensory thresholds and space motion sickness? | 5 * To what extent does the qastrointestinal system modify electrolyte and fluid balance control during space flight? | 5 * What are the compounded effects of microgravity and EVA on thermoregulatory processes and heat exchange? | How does the regulation of body temperature change during space flight? How do these changes affect the response to thermal load? | How are changes in body temperature or its regulation correlated with metabolic rate and energy expenditure? | * How does space flight affect central and/or peripheral thermoregulatory mechanisms? | Does a change in otolithic and proprioceptive activity function play a role in regulating calcium or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | How do neural mechanisms regulate homeostatic processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | 5 * What perceptual and performance changes are produced by drugs used in treatment of motion |
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Table 2

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Table 2

Listed by Category and Criticality Critical Questions

| t | 1 | ŀ | ŀ | ŀ | | | • | | | | |) | | | | | | | | | | | | | | | | | | | |
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| 5 | 읽 | 8 | 퓠 | 2 | C1 C2 C3 C4 C5 Critical Question | | Quest# | ပ | = | 2 | 3 4 | - 2 | 9 | 1 | 8 | 6 | ٦ | 0 11 | 上 | 213 | 1 | 15 | 16 | 17 | 18 | | Group w/ other | ١ | ١ | ٤ | _ |
| | _ | | (C) | 22 | 5 * How does gravity produce responses in cultured cells that mimic those seen in chronologically and | responses in cultured in chronologically and | 811112 | 4 | | | | +- | 1 | × | × | × | × | × | - | | Щ. | <u> </u> | . 2 | . 0 | | 1 | 5, 7, | 8 | | | _ |
| | | | | _ | cells, those isolated from accelerated aging | ccelerated aging | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | syndromes, and senescent cells in vitro? Which de-limiters of lifescen have released. | | | | | | | - | | | | | | | | | | | | | | | | | | | |
| | | | | | gravitational effects? | Span nave refevance to | | | * | | - | | | | | | | | | | | | | | | | | | | | |
| | | | Ω. | ις. | 5 * Is gravity a continuum in terms of stimulus/response? | orms of | 8IVa1 | 4 | | | | | | × | | _× | × | × | _×_ | W | | | | | _ | œ, | 0 | | | | |
| ī | | | r0 | ro • | 5 * What is the role of gravity in the evolution of animal gravity sensors? | in the evolution of | 8IVa2 | 4 | | | | | | × | × | × | <u>×</u> | _× | <u>×</u> | | | | | | - | ω, | 10 | | | | |
| | | | -C2 | č. | What are the basic properties and fundamental mechanisms that permit gravity sensors to adapt to an altered g-environment? | apt | 8IVa3 | 4 | | | | | | × | × | × | × | × | × | | | _ | | - | - | 80 | | | | | |
| | <u> </u> | | ro. | r. | 5 * Will animals bred for many generations in altered-g show phenotypically different gravity sensors? | ravity | 8IVa4 | 4 | | | | | | | | × | × | × | × | | | - | N | _ | - | ω_ | | | | | |
| | | | ro | 5 | What is the specific role of calcium in information processing by gravity sensors, and has this role undergone evolutionary expansion or diminution? | | 8IVb2 | 4 | | | | | | <u>×</u> | | _ <u>×</u> | × | | · | | | - | 8 | - | - | α, | 9 | | | | - (|
| | | | ro. | · c | Are the second messengers and neurotransmitters used in neural processing of information similar across species, or is there evolutionary selection for speed or for modulatory influence? | | 81Vb3 | 4 | | | | | | <u>×</u> | | | | | | | | 8 | - | _ | - | ω, | 9 | | | | |
| | | | ις. | ro • | 5 - Is there a relationship between the evolution of more mobile terrestrial forms and the evolution a more complex gravity sensing and organs. | o c | 8IVc1 | 4 | | | | | | × | | | | | | | | 2 | - | - | - | | 0 | | | | |
| | | | | | there common mechanisms that tie all gravity sensors together over evolutionary history? | that tie all gravity | | | | | | | | | | | | | | | | | | | | | | | | | |

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Critical Questions Listed by Category and Criticality

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| | | | 8IVc3 4 | | 81Vc4 4 | 8IVc5 4 | 8IVd1 4 | |
| | Question Quest# C | 5 * How do nerve fibers innervating gravity sensors 81Vc2 4 convey information about linear acceleratory forces acting on the system? What is the basis of neural coding? | 81Vc3 | What are the potential spinoffs in this work for increasing understanding of other systems by use of similar methods, or for computer technology? | | | 81Vd1 | prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) |
| | Question Quest# C | 81Vc2 | 8IVc3 ights nental | What are the potential spinoffs in this work for increasing understanding of other systems by use of similar methods, or for computer technology? | 8IVc4 | 8IVc5 nent, bstrate? | 81Vd1 | prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) |
| | Quest# C | 81Vc2 | 8IVc3 ights nental | Testing using scarce attered-g force resources? What are the potential spinoffs in this work for increasing understanding of other systems by use of similar methods, or for computer technology? | 8IVc4 | 8IVc5 nent, bstrate? | 81Vd1 | prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) |

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Critical Questions Listed by Category and Criticality

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| | | | 5 Will animals bred in microgravity or hypergravity be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are timed to a gravitational | 81743 | 4 | | | | | | × | | × | × | × | | | - | Ν | - | - | 80 | | | | | |
| | | | extreme? Is it Earth's environmental position, off an extreme, that permits adaptive responses? | | | | | - | | ·· | | | | | | | | | | | | | | | | | |
| | | | 5 Does chaos theory explain gravity sensor adaptation to an altered gravitational environment? | 81Vd4 | 4 | | ·· | | | * | × | | | | | | | -01 | | | | 60 | | | | • | |
| <u></u> | | | 5 * Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? | 81745 | 4 | | | ····· | | | × | × | × | × | × | × | <u> </u> | | N | - | | 6 0 | | | | · | |
| | | 4.7 | 5 * Does development of a gravity receptor in an altered-g environment affect the ability of the animal to mature and reproduce? | 8IVe1 | 4 | | <u>.</u> | | | | × | | × | × | × | × | | _ | | - | | ω, | 10 | | | | |
| | | 4/ | Would gravity sensors of animals bred in a sustained, altered gravitational environment be different structurally and functionally from those of animals bred on Earth? Would the changes be permanent? | 8IVe2 | 4 | | - v v. | | · | | × | | × | × | × | × | | - | ₹= | - | - | ω΄ | 0 | | | | |
| | | 4) | 5 Is there a critical time for exposure to 1-g for development of a gravity sensor with features typically associated with those of animals confined to Earth's 1-g environment? (Equal weight with 2 above.) | 81Ve3 | 4 | | | | | | × | | × | × | × | | | - | - | - | ₹ | κό | 9 | | | · | |
| | | ις. | 5 * If there is a critical period for exposure to 1-g for normal gravity sensor development, is it essential to accomplish this to provide for future plasticity and for readaptability to Earth's 1-g? | 8IVe4 | 4 | | | | | | × | | × | × | × | | | - | <u> </u> | | - | ω΄ | 9 | | | | |

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Critical Questions Listed by Category and Criticality

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| E | Cr1 | 8IVe5 an | se? 81Ve6 | 8IVf1 | 81Vf2 3n | the 8Va2 | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 |
| E | Cr1 | 8IVe5 an | se? 81Ve6 | 8IVf1 | 81Vf2 3n | the 8Va2 | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 |
| E | Cr1 | 8IVe5 an | se? 81Ve6 | 8IVf1 | 81Vf2 3n | the 8Va2 | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 |
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| | Question Quest# Cr1 | 8IVe5 an | se? 81Ve6 | 8IVf1 | 81Vf2 3n | the 8Va2 | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 |
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| | Question Quest# Cr1 | 8IVe5 an | se? 81Ve6 | 8IVf1 | 81Vf2 3n | the 8Va2 | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 |
| | Question Quest# Cr1 | 8IVe5 an | se? 81Ve6 | 8IVf1 | 81Vf2 3n | the 8Va2 | the 8Va3 | 8Vb6 chanisms, | How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 |
| | Question Quest# Cr1 | 81765 | 817e6 | ln 81Vf1 | stween 81Vf2 formation | 8Va2 | ween the 8Va3 | 8Vb6 ms, | and exocrine 8Vb8 out? Transitter | y, |
| | Question Quest# Cr1 | 8IVe5 an | Would animals bred for many generations in space 81Ve6 retain their adaptive ability to an altered-g force? Will this ability vary according to species? | • What are the mechanisms that permit central 81Vf1 adaptation to novel inputs from gravity sensors in an attered-g environment? Does rewiring take place? | What is the importance of an interaction between 81Vf2 gravity sensor input and other sensory information in total 3-D orientation, over time, of the organism? How does this change during evolution? | * How does gravity affect interactions between the 8Va2 circadian system and ultradian and infradian rhythms? | the 8Va3 | * What is the role of gravity on closed loop 8Vb6 regulatory systems (neuroendocrine, mechanisms, responsiveness, development)? | How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Chitcality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Listed by Category and Criticality Critical Questions

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| <u> </u> | ಣ | ঠ | ઇ | C2 C3 C4 C5 Critical | Question | Quest# | Ċ | 1 | 2 | 3 4 | 2 | ဖ | 2 | 80 | 6 | 10 | 11 | 12 | 13 | 4 - | 5 | 9 | 7 1 | <u>0</u> | Group w/ | | other [| Disc |
| | | | 5 | Is gravity nec does gravity a mechanisms? | essary for sex behavior? If so, how affect it and what are the | 8Vb12 | 4 | | | | | | × | × | × | × | | × | | - | 7 | - | - | <u>ග</u> | 4 | 5 | | |
| | | | 5 | Are regula environme on Earth? | atory responses to an artificial 1-g int in space equivalent to 1-g responses | 8Vb13 | 4 | | | | | | × | × | × | × | × | | | | | - | | 4 | | | | |
| | | | ب + | Is 24 hou maintain is the min presentati | * Is 24 hour per day 1-g exposure necessary to maintain normal regulatory function? If not, what is the minimum time? What are the optimal presentation characteristics of the G stimulus? | 8Vb14 | 4 | | | | | | × | × | × | × | × | - | *************************************** | - | - | .— | - | 4 | | | | |
| | | | ÷ | ls the mu organizativ and mech | * Is the musculoskeletal cyto-architectural organization and responsiveness to physiological and mechanical stimuli altered by gravity? | 8VI3 | 4 | | | | | | × | × | × | × | × | × | | | | _ | | | | | | ***** |
| | | | 5 | Is the rela necessary gravity or | Is the relationship between muscle and bone necessary for an integrated response to altered gravity or do the systems respond independently? | 8VI12 | 4 | | | | | | × | × | × | × | × | × | | | | | | | | | | |
| | | | ro • | Which me musculosk humans to mechanisr | *Which mechanisms of adaptation of the musculoskeletal systems of rats, monkeys, and humans to attered gravity are similar and which mechanisms are different? | 8VI16 | 4 | <u></u> | | | | | × | × | × | × | × | × | | | Ν | | | ^ | | | | |
| | | | + | What is the evolution protosolar | 5 • What is the degree of molecular complexity and its evolution in circumstellar, interstellar, and protosolar environments? | 11a1 | 4 | | | | | | × | × | × | | × | × | | N | N | | | - | | | | - |
| | | | * 'n | What is the inter-relation interstellar | What is the composition, structure, and inter-relationships between circumstellar, interstellar and interplanetary dust? | 11a2 | 4 | | | | | | × | | × | | | × | × | | N | | | | | | | |
| | | • | • | What is the processes pre-existing compounds elements? | e efficacy of chemical and physical in the ptotosolar nebula for altering materials and producing new and phases containing the biogenic | 11a3 | 4 | | | | | | × | | × | | | × | × | | N | | | | | | | |
| \dashv | 1 | 1 | 7 | | | | | _ | _ | _ | _ | _ | | | _ | | _ | - | _ | _ | _ | _ | _ | _ | | | | |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions Listed by Category and Criticality

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TABLE 3

ALL CRITICAL QUESTIONS WHICH REQUIRE GROUND-BASED RESEARCH

CATEGORIES

- Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral 2 manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew 3 health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- Science Specifically enabled by Moon and/or Mars Missions.
- Basic Research Not Directly Applicable to Moon and/or Mars Missions. 5
- Indicates primary category of application.

CRITICALITY

- Consensus that answer is required for Mars mission. (known effect and known problem for mission).* Criticality 1:
- Answers might be required, science basis to evaluate risk is not adequate.* Criticality 2:
- Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk. Criticality 3:
- Criticality 4: Important science which is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

11.

12

Centrifuge

Free Flyer

Lunar Base

10

| 1. | Sci | ence Readiness Levels |
|----|-----|---|
| | 1. | Only folklore of practitioners and anecdotal data available |
| | 2 | Basic scientific concept formulated |
| | 3 | Ground models developed, flight validation required |
| | 4. | Flight validation performed |
| | 5. | Countermeasures identified |
| | 6. | Countermeasures tested |
| | 7. | Operational requirements established |
| 2 | Tec | chnology Readiness Levels |
| | 1, | Technology need identified |
| | 2 | Technology and conceptual solution available |
| | 3. | Component and/or breadboard validation in laboratory |
| | | environment exist |
| | 4 | Flight validation performed |
| | 5. | Systems/subsystem prototype demonstration in a relevant |
| | | ground or space environment completed |
| | 6. | System prototype demonstrated in a space environment |
| | 7. | Actual system completed and flight qualified through test and |
| | | Demonstration |
| | 8. | Actual system "flight proven" through successful mission |
| | | operations |
| 3 | Sch | nedule (information required by) |
| | 1. | = Near term < 5 years |
| | 2 | Mid term 6-10 years |

Lunar base would be used 13. Robotic Explorer Robotic explorer would be used Other Requirements Requirement for flight resources other then those identified in 8-10 Flight Validation Required Flight validation required Not required Facilities Sufficient 16. Current ground facilities (NASA Centers, Universities and provide industry) are sufficient. Current ground facilities insufficient Community Sufficient There is a sufficient scientific community already committed or recruitable Scientific community is insufficient **Attract New Community** Activity will attract new scientists 2. — Activity will not attract new scientists
Group with other disciplines (can this activity be grouped with others from different life science disciplines?) No, cannot be grouped Do not know at this time Behavior, Performance and Human Factors 3. Regulatory Physiology 5 Cardiopulmonary

Environmental health Musculoskeletal

Cell and Developmental Biology

Neuroscience

Plant Biology

Life Support

Radiation Health

Free fiver biosatellite

SSF Centrifuge Facility would be used

- - No

Effort Required

Parallel/Alternative Path (are parallel or alternativé pathways 6 appropriate)

Far term > 10 years

Substantial

Moderate

- Yes No Ground-based
- 7. Ground-based research required
- Spacelab
 - Spacelab would be used for research
 - EDO Spacelab needed for Extended Duration Orbiter Program research
- 201 Q
 - Space Station Freedom would be used X.

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All Critical Questions Which Would Require Ground Based Research

| 5 | 8 | ខ | 8 | SS | C1 C2 C3 C4 C5 Critical Question | Quest# | 5 | 2 | က | 4 | 2 | 9 | 7 | 8 | 6 | 10 | = | 12 | 13 | 4 4 | 5 1 | 6 1 | - | 8 | Group w/ other | Disc |
|--------------|----|---|---|----|---|--------|---|--------|--------------|--------------|--------------|----------|---|---|---|----|---|----|----|-------------|----------------|----------|--------------|--------------|----------------|------|
| + - 2 | | ဇ | | | What factors should be considered (e.g. maintainability, reliability, operator discretion) when allocating functions between humans and | 1d2 | | 2 | <u>e</u> | τ- | က | ဇ | × | × | × | | | × | | | | | N | | | - |
| + | | က | | | machines? What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? | 461 | | മ | ا ال | 0 | | | × | × | × | | | × | | | - - | | | 10 | | |
| + - - | | က | 4 | rs | What are the maximum flux, the integrated fluence, and the probability of large Solar Particle Events (SPE) during any mission? | 7a4 | | Z 0 | <u>~</u> | - | ო | <u>£</u> | × | | | | | | | × | 2 | | <u>N</u> | | | |
| <u>+</u> | | • | | | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events be improved? | 7a9 | | - 2 | က | | - | - | × | × | × | | × | × | × | | 2 | _ | _ | | | |
| + | | | | S | What is the relative biological effectiveness of different types of radiation for the relevant endpoints such as cancer; cataracts? | 7f3 | | 2 4 | - | _ | _ | <u>£</u> | × | | | | | | | ··· | 2 | <u>-</u> | | - | | |
| - | ٧. | | | | What should be the radiation dose limits for manned deep space missions? | 7g1 | - | ۵ 4 | - | | | 2 | × | | | | | | | | 8 | ~ | | | | |
| + | N | | | 2 | What is the probability of cancer as a function of dose, dose rate, radiation quality, gender, age at exposure, and time after exposure? What is the effect of GCR at different stages of the carcinogenesis process? | 793 | | 24 | | <u> </u> | - | <u>E</u> | × | | | | | | | | 2 | 2 | | | | |

Table 3

All Critical Questions Which Would Require Ground Based Research

| | 8 | ပြ | C1 C2 C3 C4 C5 Critical Question | | O Message | 2 | Γ. | 6 | 6 | ۲ | l « | 1 | L | عا | Ľ | F | Ŀ | Ç | | - | | Ţ | | d | | | Γ |
|----------|----------|----------|---|----------------------|-----------|---|-------|---------------|---------------|----------|--------|----------|---|------------|---|-----|----------|---|---|----------|----------|---|---------------|------------------|----------|---|----------|
| 4 | | + | <u> </u> | and paraplace | 941 | | - - | | 十 | \dashv | \top | _ | • | <u>» </u> | 1 | = _ | _ | | 4 | Ω, | 9 . | | 2 | פֿ פ | | 등 | DISC |
| | | | Mars mission and how can storage stability in | age stability in | | | , | <u> </u> | <u>?</u> - | | | <u> </u> | | <u> </u> | | | <u> </u> | | | | _ | | _ | ယ <u>့်</u> က | 9, 10 | | |
| | | • | space be increased? What are the safety and disality consideration | accitoropiaco villa | | | | | | | | | | | | | | | | | | | | | | | |
| _ | _ | Ŭ | of storage? | | | | | | - | | | | | | | | | | | | | | | | | | |
| | | | What processes are feasible to use in a CEL | to use in a CELSS? | | | | | | | | | | | | | | | | | | | | | | | |
| | <u> </u> | ÷ | - Are additives needed? If so, which ones? | , which ones? | | | | | | | • | ł | | | | | | | | | | _ | | | | | |
| | | | - What are the storage/inventory requirements? | tory requirements? | | | | | | | | | | | | | | | | | | _ | | | | | |
| | | | - For what types of foods will storage be | storage be | | | | | | | | | | | | | | | | | | | | | | | |
| | | _ | unnecessary? | , | | | 1 | | | | | | | | | | | | | | | | | | | | |
| <u> </u> | İ | ÷ | - Is there a need for packaging? If so, which | 1? If so, which | | | | | | | | | | | | | | | | | | | | | | | |
| _ | _ | = | products will require it? | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | _ | What food processing and storage technologies | de technologies will | 9612 | _ | 4 | <u>`</u> ي | - | | _ | <u> </u> | - | > | | | > | | | | <u> </u> | , | ٠, | | | | |
| | <u> </u> | _ | need to be developed for space application? | | | | * | <u> </u> | <u>-</u> | - | | <u> </u> | | <u> </u> | | | < | | | - | - | - | _ | ກັ | 2 | | |
| _ | _ | ÷ | - How will existing and new processing and | ocessing and | | | | | | | | | | _ | | | | | | _ | | | | | | | |
| | | | storage techniques perform in the constraints | he constraints of a | | | | | | | | | | | | | | | | | | | | | | | |
| _ | _ | _ | CELSS environment? | | | | | | | | | | | | | | | | - | | | | | | | | |
| | | <u> </u> | What differences are there in product | n product | | | _ | | | | | | | _ | | | | | | - | | | _ | | | | |
| | | _ | development for space compared to land-based | 1 to land-based | | | | | | | | | | | | | | | | | | | | | | | |
| | | | activities? | | | | _ | | | | | | | | | | | | | | | | | | | | |
| | <u> </u> | <u> </u> | What are the influences of pre | ocessing, cooking, | | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | and serving on nutrient and attribute stability? | attribute stability? | | | | _ | | _ | | | | | | | | | | | | | | | | | |
| | | <u> </u> | How can processing and cookle | ing techniques be | | | | | | | | | | | | | | | | | | | | | | | |
| | | | used to modify and improve the | acceptability of | | | | : | | | | | | | | | | | - | | | - | _ | | | | |
| _ | _ | <u>=</u> | foods offered the crew? | | | | | | | | | | | | | | | | _ | | | | | | | | |
| _ | _ | _ | What are the processing requirer | | 90168 | | ۰. | | - | 0 | | <u> </u> | 6 | <u> </u> | | | > | | | <u>`</u> | _ | | Ť | | | | |
| | _ | | to handle human wastes? What are the health and | | | | | | | | - | <u> </u> | 1 | <u> </u> | | | < | | | | | | <u>-</u> - | ກັ | | | |
| | | | safety requirements for the waste treatment | ste treatment | | | | _ | | | | | | | | | | | | _ | - | | | | | | _ |
| | <u>~</u> | | subsystem? | | | | | | | | | | | | | | | | | | | | | | | | _ |

All Critical Questions Which Would Require Ground Based Research

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| | Quest# | 98425 | | Ø | ą | - | - |
| | ō | , e O | | 9f1a | 966 | 9 | 5 |
| | C1 C2 C3 C4 C5 Critical Question | Can the physico-chemical regenerative technologies and processes required for a Mars mission life support system function in the space environment? Consider: — Maintenance of liquid-gas interfaces (e.g., for nutrient delivery) — Transfers and separations of liquids, solids, and | | Can safe and sufficient supplies of water and air be provided for the trip/stay to/at Mars? Do current expendable systems exist to provide safe and sufficient supplies of water and air for the Mars mission? | Do systems exist to provide EVA/EHA capabilities required for Mars surface exploration? | What requirements should be placed on robotic and human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | What are the requirements for adequate quality of life as they relate to food, clothing, hygiene, vibroacoustics, lighting, and other personal needs (privacy, recreation) in spacecraft and habitats? |
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Ail Critical Questions Which Would Require

Ground Based Research

| ر ا | 22 | 8 | 8 | 50 1 | C1 C2 C3 C4 C5 Critical Question | Quest# | 2 | F | 2 | 3 4 | 1 | 9 | 1 | 8 | 0 | F | F | 12 | 13 | 4 | 15 | 16 | 1- | æ | Group w/ | other 7 | į |
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| 1 . | - 64 | ۲, | M | | How can traditional limitate own work | 9 | Į | Т | Τ | + | +' | 1 | | + | # | 1 | 1 | | | 1 | - | | _ | , | - 1 | | 3 |
| _ | <u>'</u> | | | | IOM CAIL LIAULIONAL IIIIIIEU-LIMB EXPOSURE AND | 482 | N | <u>ب</u> | ري د | 2 | <u>~</u> | _ | × | × | × | | | × | | | <u> </u> | ÷ | <u>-</u> | _ | | | |
| | | | | | numan toxicological data be used to predict | | | | _ | | _ | | _ | _ | | | | | | | | | _ | _ | | | _ |
| _ | | | | _ | acceptable values for inhalation and ingestion | | | | - | | | _ | _ | _ | | | | | | | _ | | | | | | |
| | | | | | exposures to single chemicals and/or to mixtures | | | | | | | _ | | _ | | | | | | | | - | | | | | |
| _ | _ | | | _ | | | _ | | | | | | | | _ | | | | | | | | | | | | _ |
| _ | | | | | conditions? | | | | | | _ | | | | - | | | | | | | | | | | | ** |
| | | _ | | _ | | | | | | | _ | | _ | _ | | _ | _ | _ | | | | | | | | | |
| | 2 | | | | What are the effects of chronic exposure to | 486 | ٥ | (r) | 0 | 3 | - | _ | <u>~</u> | <u> </u> | <u>></u> | | | > | | | - | <u> </u> | | | | | |
| | | | | _ | ultrafine and larger (respirable and nonrespirable) | | | | | _ | | _ | <u>_</u> | <u> </u> | <u> </u> | _ | | < | | | | | | n | | | |
| | | - | | | narticles on crew beath estate and | | | | | - | | _ | | _ | | | | | | • | | | | | | | |
| | | | | | Tangles of close floatili, salety, all | | | | | _ | | _ | | _ | | | | | | | | | | | | | |
| _ | | | _ | _ | pertormance? | | _ | | | | | _ | | | | | | | | | | | - | | | | - |
| * | | - | | | What approaches may be used when insufficient | 4.9.7 | · | | | | | _ | > | | | | | | | | | _ | | | | | _ |
| _ | | _ | _ | <u> </u> | data are available to allow prediction of population | · | | | _ | | | | <u><</u> | | | | _ | | | | | _ | <u>.,</u> | | | | |
| | | _ | | | and an extension to allow production of accordingly | | | | | _ | | | | | | | | | | _ | | | | | | | |
| | _ | | | _ | exposure levels? | | | | _ | _ | | | | | | | | | | | | | | _ | | | |
| * | | 4 | _ | | What is the effect of space flight on ail | 442 | ۰ | | 9 | - | ٥ | _ | > | > | > | > | > | > | _ | | | | | | | | |
| | | | | | microorganisms? | | _ | <u>. </u> | | | | - | < | <_ | < | <u><</u> | < | < | | | _ | =- | _ | <u>-</u> | | | |
| | | | | | | | | _ | _ | _ | | | | _ | | | | | | | | | | | | | |
| - | <u>ო</u> | | | | What technology is available to identify | 4P4 | N | <u>در</u> | 3 | 2 | - | | × | × | × | | | × | | | | | | - | | | |
| | | | | _ | microorganisms in crew and environmental (air. | | | | | | _ | _ | | <u> </u> | <u>_</u> | | | : | | | | | _ | - | | | |
| | | _ | | | water, surfaces) specimens. How are | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | _ | | | | | | | | | | | | | | | | |
| | | | | _ | incroolganisms controlled by anti-microbia | | | | | _ | | _ | | _ | | | | | | | _ | | _ | | | | - |
| | | | | _ | procedures? | | | _ | | | | | | | | | | | | | | - | | | | | |
| - | က | 4 | - | _ | What, if any, are the interactions between the | 401 | ~ | <u>e.</u> | ~ | ٥ | 0 | • | > | | > | | | > | | | <u>`</u> | | • | | | | |
| | | | | <u> </u> | effects of microgravity on crewmembers and the | | _ | | | | _ | - | <u>:</u> | | <u> </u> | | | < | | | - | | _ | 0 | | | |
| | | | _ | 4 | Affects of off-baseline levels of othershorts | | _ | • | | _ | | | _ | | , | | | | | | | | | _ | | | _ |
| | | | | _ | | | | | _ | | | | _ | | | | | | | | | | | | | | |
| | | | | _ | parameters, including gas composition, pressure, | | | _ | | | _ | | _ | | | | | | | | | _ | _ | | | | |
| | | | | w | and temperature? | | | | _ | | _ | | | | _ | | | | | ** | | | | | | | |
| + | | | - | _ | What are the officers of all actuals are taken | ı | | | | | | _ | | | | | | | | | _ | | | | | | |
| _ | | _ | - | _ | indicate the elects of all potential atmospheric | 405 | N | 2 | <u>ო</u> | <u>ო</u> | <u>-</u> | _ | × | × | × | | | × | | <u> </u> | <u>-</u> | Ξ | _ | က | | | |
| | | | _ | <u>.</u> | components, including contaminants and factors on | | _ | | | _ | | _ | | | | | | | | | | | - | | | | |
| | | _ | | <u>a</u> | physical and psychological well-being and crew | | | _ | | | _ | | | | | | | | | | | | | | | | |
| _ | | | | | performance? | | | | | | | _ | | | | | | | | | | | | | | | |
| • | _ | | _ | | What are the confole multiplicities at are tall | - | _ | | | (| | _ ! | | | | | | | | | | _ | | | | | |
| | | | | | interaction products? | 50/ | N. | 5 | | N | _ | Σ_ | <u>×</u> | | | | | | | | 2 | <u> </u> | - | _ | | | |
| + | 1 | 4 | \dashv | 1 | | | 7 | | - | | - | _ | | | | | | | | _ | | - | _ | | | | _ |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Ci=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Paralle/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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All Critical Questions Which Would Require Ground Based Research

| Question | | Quest# | | | | | | <u>ن</u> و | | 8 | 6 | 0 - | - | 2 13 | 3 14 | | 9 | 7 | 8 7 | Group | w/ of | other | Disc |
|----------|---|---------------|----|----------|----|--------------|--------------|------------|---|---|---|-----|---|----------|------|--------------|----|--------------|--------------|-------|-------|-------|------|
| | How is a radiation field transformed as a function of depth in different materials? | 7b 4 | | ო | 2 | <u>- 2</u> | <u>г</u> | <u> </u> | | | | | | | | 8 | | - | - | | | | |
| | What are the thresholds required for gravity to have an effect? | 8la4 | 2 | N | 9 | - 2 | - | <u>E</u> | × | × | × | × | | | | | 8 | α | | | | | |
| • — | What are the differences, if any, between species and their tissues in their perception and responses to gravity? | 8la6 | 2 | - | 2 | - | | <u>£</u> | × | × | × | × | | | | - | α' | 8 | _ | | | | |
| | Can plants successfully reproduce through more than one generation in space? | 8 lb 1 | 2 | с | - | - | | <u>£</u> | × | × | × | × | | | | - | N | ر ا | - | 2 | | | |
| | Is chromosomal integrity and behavior during cell division affected in microgravity? | 8152 | N | 4 | 9 | - | | 2 | × | × | × | × | × | | | | 7 | N. | - | 0 | | | |
| 0 | is cell, tissue, or organ differentiation affected in microgravity? | 8163 | 7 | - | - | - | 2 | <u>E</u> | × | × | × | × | | | | _ | 2 | N | _ | | | | - |
| 끝도로 | What effect does microgravity have on embryogenesis and the ensuing stages of the life cycle of plants from maturity to flowering and senescence? | 8 lb 4 | N | +- | T- | - | 2 | <u>£</u> | × | × | × | × | | | | | 8 | 8 | - | | | | |
| ·≝ | Are microgravity-grown tissues and organs competent? | 8165 | 0 | - | _ | - | 2 | 2 | × | × | × | × | × | | | | 8 | 8 | _ | | | | |
| 三百 | Are the growth rates of higher plants or single cells affected by microgravity? | 8166 | ٧. | 0 | 21 | - | 2 | <u> </u> | × | × | × | × | | , | | | 8 | 8 | - | 12 | | | |
| .∺ 5 ± × | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | 8168 | Ν | _ | N | - | - | 2 | × | × | × | × | × | <u>×</u> | | - | 0 | 0 | - | o o | | | |
| .9 | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered in microgravity? | 81c1 | N | N | N | - | - | 2 | × | × | × | × | | | | | N | 7 | - | 2 | | | |
| | What effect does microgravity have on the synthesis of storage and support polymers? | 81c2 | 7 | 2 | 2 | - | - | <u>E</u> | × | × | × | × | | | | _ | α | 2 | + | 2 | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Cniticality
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

All Critical Questions Which Would Require Ground Based Research

Table 3

| Ω 0 | 22 | ည ပ | 4 | CS | C2 C3 C4 C5 Critical Question | Quest# | 5 | - 2 | 8 | 4 | 2 | 9 | 1/8 | 6 | F | E | 12 | 13 | 14 | 151 | 161 | 누 | 8 | Group | w/ other | Disc |
|----------|-------------|--------|----------|----------|---|--------|----------------|----------|--------------|---|---|---------------------------------------|-------------|-----------------|----------|--------------|----|----|----------|-----|---------|--------------|----------|-------|----------|------|
| * - | | | | | Are pathways for plant nutrient absorption altered in microgravity? | 81c4 | 2 | - | - | - | - | Œ | × | × - | × | | | | <u> </u> | 1 2 | | +- | | | | |
| • | | | · | | What are the effects of the space environment on long distance transport of water and on transpiration? | 8105 | ~ | | | | _ | <u>£</u> | <u>×</u> | <u>×</u> | <u>×</u> | | | | • | - 2 | 01 | | | | | |
| <u>,</u> | က | 4 | | | How is the effect of gravity (and microgravity) on cells influenced by magnetic fields and radiation? | 8IIc1 | 2 | | - | - | 0 | <u>ი</u> | × | <u>×</u> | × | × | × | × | | | - 81 | - | <u> </u> | 1 | | |
| <u>.</u> | | 4 | | | The | 9a1 | 2 | <u>ო</u> | 0 | _ | | | × | <u>×</u> | × | × | × | | | _ 2 | <u></u> | | <u>,</u> | . ,01 | = | |
| | | - | | | studying this question: Closed environments | | - | | | | | · · · · · · · · · · · · · · · · · · · | ··· | | | | | | | · | | | | | | |
| | | | | | Recycling Limited space | | · | | | | | | | _ | | | | | | | | | | | | |
| - | | | <u> </u> | | Gravity effects Phytorepic volatile communds and what the community is a community and what the community is a community and community and community and community is a community and communi | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Contaminants | | | | - | | | | | | | | | | | | - | | | | | |
| | | | | | Hadiation Adventitious biota (microbial and other) | | - | | | | | - | _ | | | | | | | | | | | | | |
| • | | 4 | | | 70 | 9a3 / | - 3 | <u>ო</u> | | N | _ | - | <u> </u> | X | × | | × | | | - 2 | | | 9 | 10. | = | |
| | | | | | generating and water recycling capacity of crop plants? The following factors represent the | | | | | | | | | | | | | | | | _ | | | | | |
| | | | | <u>_</u> | minimum that should be considered in studying this question: | | | | | | | | | | | | | | | - | _ | | | | | |
| | | | | | Light quantity, quality, periodicity, gas | | | | | | | | | | | | | | | | | | | | | |
| | | | | | _ | • | | | | | _ | | | | | | | | _ | _ | | | | | | |
| | _ | | | | volume, temperature, etc. | | | | | | | | | | | | | | | - | | | | | | |
| | | | | <u> </u> | Aerial environment: gas composition and | | | | | | | | | | | | | | | - | _ | | | | | |
| \dashv | | | | | pressure, temperature, planting density, etc. | | | | | | | | | | | | | | | | | | | | | |

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All Critical Questions Which Would Require Ground Based Research

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| Group w/ other | - | , | _ | | | | | | | | | | 6,7 | | | | | | | | | | |
| ≩ | 6, 10, 11 | | 6, 10, 6 | | | | | | | | | | 'n, | | | | | | | | | | |
| Jog | 7, | , | Ę. | | | | | | | | | | 4, | | | | | | | | | | |
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| 171 | _ | | | | | - | _ | | | | | | | | | | | _ | | | | | |
| 161 | <u>-</u> | | <u></u> | _ | _ | | _ | | | _ | | _ | - | | | | | | _ | | | | |
| 151 | 2 | | Ν | _ | | | - | | _ | | | | _ | | | | | _ | | | | | |
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| 121 | | | | - | | _ | | | | | | | × | | | | _ | _ | | | | | _ |
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| S | 1 | | | | | | | | | | | | | | | | | | | | | | |
| Quest# | 9a4 | | 9a7 | | | | | | | | | | 8 9 6 | | | | | | | | - | | |
| Question | What are the effects of adventitious biota 9a4 | (microbial and other) over long periods in a CELSS? | lowing | alternative food sources in a CELSS? | — Animals (aquatic and terrestrial, vertebrate | and invertebrate) | Algae | — Fungi | - Bacteria | - Non-traditional higher plants | — Tissue-cultured cells | - Synthetics | What are the specific nutritional requirements for 9b8 | humans in space? This question should consider at | least the following: | Caloric requirements | Will the nutritional requirements of the crew | change and require modified diets over time of | flight | — Fluid requirements | Distribution of the macro nutrients (protein, | carbohydrate. lipid) | |
| Question | What are the effects of adventitious biota | (microbial and other) over long periods in a OELSS? | What is the potential for using the following | aternative food sources in a CELSS? | — Animals (aquatic and terrestrial, vertebrate | and invertebrate) | Algae | - Fungi | - Bacteria | - Non-traditional higher plants | — Tissue-cultured cells | - Synthetics | What are the specific nutritional requirements for | humans in space? This question should consider at | least the following: | Caloric requirements | Will the nutritional requirements of the crew | change and require modified diets over time of | flight | — Fluid requirements | Distribution of the macro nutrients (protein, | carbohydrate. lipid) | |
| Question | | (microbial and other) over long periods in a CELSS? | | alternative food sources in a CELSS? | Animals (aquatic and terrestrial, vertebrate | and invertebrate) | - Algae | - Fungi | - Bacteria | Non-traditional higher plants | - Tissue-cultured cells | - Synthetics | for | humans in space? This question should consider at | least the following: | - Caloric requirements | Will the nutritional requirements of the crew | change and require modified diets over time of | flight | Fluid requirements | Distribution of the macro nutrients (protein, | (carbohydrate, lipid) | |
| Question | What are the effects of adventitious biota | (microbial and other) over long periods in a OELSS? | What is the potential for using the following | alternative food sources in a CELSS? | — Animals (aquatic and terrestrial, vertebrate | and invertebrate) | - Algae | - Fungi | - Bacteria | — Non-traditional higher plants | - Tissue-cultured cells | - Synthetics | 4 What are the specific nutritional requirements for | humans in space? This question should consider at | least the following: | - Caloric requirements | Will the nutritional requirements of the crew | change and require modified diets over time of | flight | — Fluid requirements | Distribution of the macro nutrients (protein, | carbohydrate. lipid) | |
| | What are the effects of adventitious biota | (microbial and other) over long periods in a CELSS? | What is the potential for using the following | alternative food sources in a CELSS? | — Animals (aquatic and terrestrial, vertebrate | and invertebrate) | - Algae | - Fungi | - Bacteria | Non-traditional higher plants | Tissue-cultured cells | - Synthetics | What are the specific nutritional requirements for | humans in space? This question should consider at | least the following: | - Caloric requirements | Will the nutritional requirements of the crew | change and require modified diets over time of | flight | Fluid requirements | Distribution of the macro nutrients (protein, | carbohydrate. lipid) | |

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All Critical Questions Which Would Require Ground Based Research

Table 3

Table 3 All Critical

All Critical Questions Which Would Require Ground Based Research

| ਹ | 22 | 8 | 8 | S | C1 C2 C3 C4 C5 Critical Question | Quest# | 5 | <u> </u> | 2 3 | 4 | 2 | 9 | _ | 8 | 6 | Ĕ | ٦ | 12 | 2 13 | 二 | 4 15 | 5 16 | 6 17 | 7 18 | 8 Group | Group w/ other | | Disc |
|--------------|----|---|---|---|---|--------|-----|--|-----|----|---|---|---|----------|------|-----|---|----|---------------------------------------|---|--------------|------|--------------|----------|---------|----------------|---|------|
| * | | | 4 | | What will be the acceptability thresholds for revitalized air in an operational CELSS? | 9028 | 2 | е е | 6 | 2 | 2 | - | × | <u> </u> | × | | | × | ļ | | - | - | - | - | 3, 6 | | | |
| * | | | 4 | | What currently available air treatment technologies can be adapted to a CELSS use, and what technologies will need to be developed for space application? | 9029 | N N | <u>က</u> က | | _0 | N | | × | × | × | ··· | | × | | | - | ₩. | <u> </u> | <u>-</u> | ဗ ဗ | | | |
| * | | | 4 | | What strategies or techniques exist for monitoring and control of the known or suspected possible | 9431 | 0 | - 2 | | ~ | 0 | - | × | × | × | | | × | · · · · · · · · · · · · · · · · · · · | - | - | Ν | | | რ 4 | 5, 6, 7 | _ | |
| | | | | | causes of the support system instability? Consider: | | | | | | | | | 1 | | | | | | | | | | | | | | ı |
| | | | | | Pests or pathogens (disease) SMACS | | | | | | | | | | | | | | | | | | , | | | | | |
| | | | | | Toxicants produced by humans, by processing procedures, or by the plants themselves | | | | | | | | | | | | | | - | | | | | | | | | |
| | | | | | Atmosphere leakage Perturbations in environmental controls | - | | | | | _ | | | | ···· | | | | | | | | | | | | | |
| | | | | | Radiation Micrographity | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | — Unanticipated ecological interactions | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Scheduled of unscheduled system or mission events | | | | | | | _ | | | | | | | | | | | | | | | | |
| | | - | | | Failure of microbial cultures in algal fermentation systems | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | - Food variety | | | | | | | | | | | | | | | | | | | | | | | |

All Critical Questions Which Would Require Ground Based Research

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| C1 C2 C3 C4 C5 Critical | What are the requirements for CELSS system design and operation to achieve safe and reliable operation? Address the following: — Subsystem redundancy - Interaction with Chemical - Physical regeneration — System modeling and behavior — Alternative strategies for system monitoring and control — Failure of a subsystem | Is a CELSS, because it operates within a limited volume and intense dynamics, subject to unknown or poorly characterized instabilities, such as chaotic behavior? | What are the thresholds of system size (minimal) and system safety and reliability (maximal), and can these be extended in an integrated, controlled system? | How can mathematical models be utilized to aid system design, system simulation, and system operations? | What are the power requirements and launch mass and volume for an operational CELSS? | What sensors are required for automation of a CELSS? | What is the productivity, transpiration, and dry matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | What is the morphology and reproductive capability of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for space bases? |
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All Critical Questions Which Would Require Ground Based Research

Table 3

All Critical Questions Which Would Require Ground Based Research

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| | spectra of | e existing for dia be extended to ost living cells? | and other Jiaries alter the ? | n related to | to produce on DNA? | activation and involved in the ation? | modulating r level (repair, on, etc.)? | f radiation ects in whole | neoplastic cell ing to a | s modulate arged particles? | adiation damage whole organisms? | to extrapolate |
| itical Question | hat are the yields and energy sctrons? | w can the wealth of knowledg ergy deposition in gaseous me iliquid phase applicable to mo | w do diffusion, recombination eractions of chemical intermeremical events at the DNA level | w is physical energy depositio ilogical effect? | nat are the probabilities of GCR liation damage at specific sites | w are processes like oncogene cogene suppressor inactivation cinogenic effects of GCR radia | at mechanisms are involved in iation damage at the molecula ors in repair, gene amplificati | w can molecular mechanisms o nage be used to understand eff is? | at is the probability of initiating insformation or other steps lead icerous cell? | do cellular repair mechanisms nage produced by energetic ch. | v can cellular mechanisms of raused to understand effects in v | v can animal models be used to babilities of radiation risk to h |
| 1 1 | What are the yields and energy spectra of electrons? | How can the wealth of knowledge existing for energy deposition in gaseous media be extended to the liquid phase applicable to most living cells? | | How is physical energy deposition related to biological effect? | What are the probabilities of GCR to produce radiation damage at specific sites on DNA? | How are processes like oncogene activation are oncogene suppressor inactivation involved in carcinogenic effects of GCR radiation? | What mechanisms are involved in modulating radiation damage at the molecular level (repair, errors in repair, gene amplification, etc.)? | How can molecular mechanisms of radiation damage be used to understand effects in whole cells? | What is the probability of initiating neoplastic transformation or other steps leading to a cancerous cell? | How do cellular repair mechanisms modulate damage produced by energetic charged particl | How can cellular mechanisms of radiation damage be used to understand effects in whole organisms? | How can animal models be used to extrapolate probabilities of radiation risk to humans in space? |
| 1 1 | 5 What are the yields and energy electrons? | 5 How can the wealth of knowledg energy deposition in gaseous metho liquid phase applicable to mo | How do diffusion, recombination a interactions of chemical intermed chemical events at the DNA level | 5 How is physical energy depositio | 5 What are the probabilities of GCR radiation damage at specific sites | 5 How are processes like oncogene oncogene suppressor inactivation carcinogenic effects of GCR radia | What mechanisms are involved in radiation damage at the molecula errors in repair, gene amplificati | 5 How can molecular mechanisms o damage be used to understand efficells? | What is the probability of initiating transformation or other steps lead cancerous cell? | 5 How do cellular repair mechanisms damage produced by energetic ch | 5 How can cellular mechanisms of rate be used to understand effects in v | 5 How can animal models be used probabilities of radiation risk to h |
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| C1 C2 C3 C4 C5 Critical Question | | | | | | | | | | | | |

Table 3 Page 12

All Critical Questions Which Would Require Ground Based Research

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| | | | | developmental detriment incurred as a consequence of radiation exposure in space? | | | | | | | | | | | | | | | | | | | | | | | | |
| - 2 | | | | What is the role of gravity in the regulation of | 8Va1 | က | | - | 1 | 2 | ო | × | × | × | × | | | | | _ | 8 | | 4 | _ | | | | |
| | | | | circadian rhythms? — What are the effects of the absence of gravity | | | | | | | | | | | | | | | | | | | | | | | | |
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| | | | | amplitude and/or waveform) and entrainment of | | | | | | | | | | | | | | | - | | | | | | | | | |
| | | | | circacian inythms? — Is it at the synchronizing agent (zeitgeber)? | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | — If not, is it necessary for the action of other | | | | | , | - | | | | | | | | | | | | | | | | | | |
| | | | | synchronizing agents (light, exercise)? | | | | | | | | | | | | | | | | | | | | | | | | |
| | | _ | | What is the role of gravity in the ontogeny of | | | | | | | | | | | | | | | | | | | | | | | | |
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| | | | | complex organisms? | | | | | | | | | | | | | | | | | | - | | | | | | |
| | | | | - What is the gravity threshold for it actions in | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | the regulation of circadian rhythms? Does this | | | | _ | | _ | | | | | | | | | | | | | | | | | | |
| | | | | gravity threshold vary with the complexity of the | | | | | | | | | | | | | | | | | | • | | | | | | |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Table 3 Page 14

All Critical Questions Which Would Require Ground Based Research

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| Question | ling po (for ty | foods and/or ingredients be derived lible plant wastes? e the crop plant-specific limits of this | lable materials be minimized in | | 0 | currently available waste treatment/nutrient sration technologies can be adapted to a S use, and what technologies will need to be sped for space application? (Note question | s that |
| Question | echnology, including ed to develop crop in space? (for and bioavailability ire | | | What are the processing requirements necessary to convert metabolic wastes into nutrients suitable for plant growth? | position of the 9c. gard to the | ŧ | |
| Question | How can molecular genetic technology, including germplasm screening, be used to develop crop cultivars better fit for CELSS use in space? (for example) — Improve nutrient quality and bioavailability — Reduce natural toxicants — Optimize plant architecture | Can edible foods and/or ingredients be derived from non-edible plant wastes? — What are the crop plant-specific limits of this capability? | How will non-recyclable materials be minimized in a CELSS program? | What are the processing requirements necessary to convert metabolic wastes into nutrients suitable for plant growth? | What will be the limits of the composition of the processed waste streams with regard to the following parameters: — Organic an inorganic materials — Potentially toxic materials — Water content? | What currently available waste treatment/nutrient regeneration technologies can be adapted to a CELSS use, and what technologies will need to be developed for space application? (Note question 16.8) | What are the production rates and chemical compositions of the different waste streams that are to be processed in a CELSS? |
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All Critical Questions Which Would Require Ground Based Research

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| + | | * | 4 | Can plant transpiration water qualify as potable and hygiene water? If not, what currently available water treatment technologies can be adapted to polish transpiration water in a CELSS, and what technologies will need to be developed for space annication? | 9c24 | ₀ | - | - | <u>-</u> | N | Ψ | × | | × | | | × | | - | | | | <u>е</u> | φ. | | | | |
| * | | | 4 | If the crop plants in a CELSS can be used to meet the production rate demands for potable and hygiene water, then what types and numbers of plants will be required, and what environmental conditions will these plants require? | 9625 | ო | <u>ک</u> ۵ | <u> </u> | α | N | + | × | × | × | | | × | ** | | | N | | <u> </u> | 6 | | | | |
| - | | · · · · · · · · · · · · · · · · · · · | 4 | What currently available water treatment technologies can be adapted to recycling the various grades of water (hygiene, wash, etc.) in a CELSS and what technologies will need to be developed for space application? | 9000 | ო | 8 | | N | N | - | × | × | × | | | × | | V | - | N . | _ | | ဖ က် | | | | |
| 4 | | | 4 | What types and surface area of plants will be required to meet the production rate demands for revitalized air and what environmental conditions do these plants require? | 0000 | <u>ო</u> | N N | <u>£</u> | 8 | 0 | - | × | × | × | × | | × | | | - | 0 | | ,, | မ် လ | | | | |
| * | | · · | 4 | What robotic and automated procedures should be developed for control, monitoring, and operations? | 2EP6 | <u>წ</u> | - | က | - | N | _ | × | | × | | | × | | | _ | ~ | | + | က် ထိ | Ξ | | | |
| - | | • | 4 | Can proposed food processing techniques be modified to work effectively at reduced gravity? | 9644 | 6 | 2 | | N | 8 | - | × | × | × | | | × | | <u> </u> | - | <u>.</u> د | - | | 10, 1 | Ξ | | | - |
| - | <u>ෆ</u> | <u> </u> | | Can wastes be successfully disposed of on a Mars mission without impacting planetary protection? | 9f3a | <u>ار</u> | 7 | ~ | m | ,- | | × | | × | | | × | | · · | _ | o. | _ | - | ა, ი | | | | |
| - | <u>е</u> | | | Do regenerative systems exist to provide safe and sufficient supplies of food for the Mars mission? | 9f4c | 8 | 3 | 2 | | - | - | <u>×</u> | | × | | | × | | | " | 2 | - | - | 3, 6 | | | | |

Table

All Critical Questions Which Would Require Ground Based Research

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| Question Quest# C | onitor food 9f5f | of 10 2 3 | rdes 5c12 | What is the precise energy deposition of heavy 7c1 ions? | How can the radiation effects on cells in culture be 7e5 related to radiation effects in "normal" cells and tissues? | 1a9 | 161 | 117 | 191 |
| Question Quest# C | onitor food 9f5f | What provisions must be taken during the course of 10 2 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | rdes 5c12 | What is the precise energy deposition of heavy 7c1 ions? | How can the radiation effects on cells in culture be 7e5 related to radiation effects in "normal" cells and tissues? | How does prolonged space flight affect behavior 1a9 and group dynamics (including species, sex, and age differences)? | What are the factors involved in integrating 1d1 automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and countermeasures for particular missions? | What are the criteria for evaluating individual and 117 crew performance and productivity during space missions of various durations? | What are the effects of stress on crew and ground 1g1 team performance and what method of detection and intervention strategies (e.g. selection, training, crew support) would prove effective? |
| C2 C3 C4 C5 Critical Question Quest# C | Do automated systems exist to monitor food 9f5f safety/quality for Mars mission? | What provisions must be taken during the course of 10 2 3 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | What are the appropriate light wave length cycles 5c12 to maximize vitamin D production? | What is the precise energy deposition of heavy 7c1 ions? | How can the radiation effects on cells in culture be 7e5 related to radiation effects in "normal" cells and tissues? | 4 How does prolonged space flight affect behavior 1a9 and group dynamics (including species, sex, and age differences)? | What are the factors involved in integrating 1d1 automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and countermeasures for particular missions? | What are the criteria for evaluating individual and 117 crew performance and productivity during space missions of various durations? | 191 |
| Question Quest# C | Do automated systems exist to monitor food 9f5f safety/quality for Mars mission? | What provisions must be taken during the course of 10 2 3 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | What are the appropriate light wave length cycles 5c12 to maximize vitamin D production? | What is the precise energy deposition of heavy 7c1 ions? | How can the radiation effects on cells in culture be 7e5 related to radiation effects in "normal" cells and tissues? | *3 4 How does prolonged space flight affect behavior 1a9 and group dynamics (including species, sex, and age differences)? | *3 4 What are the factors involved in integrating automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and countermeasures for particular missions? | *3 4 What are the criteria for evaluating individual and 117 crew performance and productivity during space missions of various durations? | *3 What are the effects of stress on crew and ground 1g1 team performance and what method of detection and intervention strategies (e.g. selection, training, crew support) would prove effective? |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

All Critical Questions Which Would Require Ground Based Research

Table 3

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| | Critical Question Quest# C | - | rent input to the 6e1 1 e and somato-sensory n tong-duration flights lex deficits? | N | 161 | 1b2 2 | d cognisant performance 1d7 2 ants of humans in flight as a function of duration, gravity field, | seded for analyzing missions 1f1 2 uman performance (e.g. task nd models)? | uipment requirements 113 2 lipment requirements for (EVA)? |
| | Critical Question Quest# C | What are specific countermeasures that impact 5c3 1 effectively upon bone and connective tissue structure and function? | Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with tong-duration flights result in permanent reflex deficits? | 1a6 2 | 101 | 162 2 | ance 1d7 2 of ield, | 1f1 | 1f3 2 |
| | Critical Question Quest# C | 5c3 1 | 661 | 1a6 2 | 101 | 162 2 | ance 1d7 2 of ield, | 1f1 | 1f3 2 |
| | Critical Question Quest# C | 4 What are specific countermeasures that impact 5c3 1 effectively upon bone and connective tissue structure and function? | Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with hong-duration flights result in permanent reflex deficits? | * What are the critical characteristics of leaders 1a6 2 that effect reciprocity and productivity of crews? What are the optimal crew command structures for a Mars mission? | What psychological and behavioral characteristics 1b1 are exclusary? What behavioral and psychometric criteria should be used for selecting candidates for a Mars mission? | • What are the protocols for training effective 1b2 2 ground teams and space crews in problem solving, enhanced communication, crew coordination, and interpersonal dynamics? | What are the physical and cognisant performance 1d7 2 capabilities and requirements of humans in different stages of space flight as a function of mission parameters, e.g. duration, gravity field, physical environment? | What procedures are needed for analyzing missions 1f1 2 for their demands on human performance (e.g. task analytical techniques and models)? | • What are the special performance requirements 1f3 2 and capabilities and equipment requirements for extravehicular activity (EVA)? |
| | Question Quest# C | What are specific countermeasures that impact 5c3 1 effectively upon bone and connective tissue structure and function? | Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with fong-duration flights result in permanent reflex deficits? | What are the critical characteristics of leaders 1a6 2 that effect reciprocity and productivity of crews? What are the optimal crew command structures for a Mars mission? | What psychological and behavioral characteristics 1b1 are exclusary? What behavioral and psychometric criteria should be used for selecting candidates for a Mars mission? | What are the protocols for training effective 1b2 2 ground teams and space crews in problem solving, enhanced communication, crew coordination, and interpersonal dynamics? | What are the physical and cognisant performance 1d7 capabilities and requirements of humans in different stages of space flight as a function of mission parameters, e.g. duration, gravity field, physical environment? | What procedures are needed for analyzing missions 1f1 for their demands on human performance (e.g. task analytical techniques and models)? | What are the special performance requirements 113 2 and capabilities and equipment requirements for extravehicular activity (EVA)? |

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| Quest# | 1111 | - + + 1.5 | 193 | 3a1 | 3a2 | 3a21 |
| C1 C2 C3 C4 C5 Critical Question | p influence sh mission sloped to | improve performance and productivity? What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological changes incurred in space affect task performance? | actors that shape individual and team I the ability to cope effectively with stress? | Of the various countermeasures available to combat adverse cardiovascular effects on longand short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, | isms underlying the ved after flight? ormeasures for this? | What is the relationship between cardiovascular response and exposure to varying gravity levels (force, internal frequency and time interval 12 le |
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All Critical Questions Which Would Require Ground Based Research

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| | | | | | atmospheric environments, including the impact of | | | | | | | - | | | | | | | | | | | | | | | |
| | | | | | microgravity, and how can countermeasures be | - | | | | | - | | | | | | | | | | | | | | | | _ |
| | | | | | utilized against these deteriorations? | | | | | | | | | _ | | | | | | | | | , | (| | | |
| | 2 | က | 4 | | What is the time course and extent of muscle | 5a1 | 2 | <u>e</u> | _ | - | د | <u>×</u> ~ | × | × | × | <u>×</u> _ | | | _ | | _ | | · | χo | | | |
| | | | | | atrophy during either prolonged spaceflight or | | | | _ | | | | | | | | | _ | | | | | | | | | |
| _ | | | | | unloading? | | | | | | | | | | | | | | | | | | | | | | |
| | · N | က | 4 | | How is muscle metabolism regulated during normal | 5a2 | 2 | <u>ო</u> | _ | _ | - | × e | × | × | × | <u> </u> | <u>~</u> | | _ | _ | - | _ | ω, 4, | 'n, | _ | | |
| | | | | | activity and exercise, after acute and chronic | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | unloaded states, and during recovery from | _ | | | | | | | | | | | | _ | | | | | | | | | |
| | | | | | unloading? | | | | | | | | | | | | | | | | | | | | | | |
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| | V | | + | _ | אוויפון קופ חופ פוופרוס כו שופופס ופאפוס כו וויפווייפון | | | | | _ | | | | | | _ | | | | | _ | | | | | | |
| _ | | | | | and their receptors in regulating the physiology of | | | _ | | | | | | _ | | | | | | | | | | | | | |
| | | | | _ | unloaded muscle? | | | _ | | | | | | | | | | | | | | | | | | | _ |
| | 2 * | | 4 | _ | What is the link between mechanical activity | 5b4 | 2 | 2 | _ | - | - | × ຕ | <u>×</u> | × | × | <u> </u> | | | ~ | _ | _ | | ر, ان | œ | | | |
| | | | | | (stress) and hormonal state in regulating protein | | | | | | | | _ | | | | | | _ | | | | | | | | |
| | | | | | turnover and gene expression and structure and | | | | | | | _ | | | | | | | | _ | | | | | | | |
| 1 | | | | | function of muscle, as investigated by both | | | | | | _ | | | | | | | | | | | | | | | | |
| | | | | | ground-based and flight experiments? How can | | | | | | | _ | | | | | | | | | | | | | | | |
| | | | | | this information be used to integrate | | | | | | | | _ | | | | | | | | | | | | | | _ |
| | | | | | neuromuscluar and musculoskeletal models of | | ; | | | | | | | | | | | | | _ | | | | | | | |
| | _ | _ | | | mechanics and adaptation to develop | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | countermeasure protocols? | | | | | | | | | | | | | | | | | | - (| | | | |
| .— | 2 | _ | 4 | | What are the effects of unloading on the muscular | 5b6 | 2 | <u>ო</u> | N | - | _ | <u>က</u> | × × | <u>×</u> | × | | × | | _ | _ | | _ | _ | | | | _ |
| | | | | | intracellular and extracellular matrix? | | | | | | | T | \dashv | \dashv | _ | | \dashv | \dashv | 4 | 4 | _ | | | ١ | ١ | | ٦ |

All Critical Questions Which Would Require Ground Based Research

Table 3

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| C1 C2 C3 C4 C5 Critical Question | 1 X 20 % E | site? To changes in regional microcirculation? To other regional and systemic factors? Which endocrine and nutritional processes are required for maintenance of bone and connective tissue? How do these processes interact with mechanical loading? Are these processes affected by space-flight? | Is bone loss reversible in terms of mass, ultra- and micro-structural organization, and microstructure? To what extent do irreversible architectural adaptations affect structural integrity? | How does mechanical stress and changes in stress contribute to bone and connective tissue formation? Are stress and/or changes in stress required for continued structural integrity? | What are the critical characteristics or components of normal daily tissue stress and strain histories that regulate bone and connective tissue development, maintenance, and adaptation? How are these characteristics affected by microgravity? | How are regional changes in bone and connective tissue related to regional changes in muscle tissue? |
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All Critical Questions Which Would Require Ground Based Research

Table 3

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| | 15 | 3 | [3 | 5 | Calcalcalcal Critical Question | Quest# C | 41 | 2 | 3 4 | 2 | 9 | 2 | 8 | თ | <u> </u> | = | 2 | 3 17 | 4 15 | 16 | 17 | 18 | | Group w/ | / other | Disc |
| 5 | | 3 | 4 | | How are neuromuscular activation patterns and | 5c11 2 | 2 | 2 | - | - | က | × | × | × | × | × | | | - | <u></u> | <u> </u> | _ | 7, | 3, 8 | | |
| | | | | | musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to | | | | | | | | | | | | | | | | | | | | | |
| | | | | | 1-9? | | | | , | | • | > | > | > | > | <u> </u> | | | 0 | _ | _ | | 6 | . 8 | | |
| | * 0 | | 4 | | What are the patterns of in-vivo mechanical | Z | <u>n</u> | ກ_ | <u>-</u> - | | <u> </u> | <u> </u> | < | | < | | | _ | 1 | | | . ! | | | | |
| | | | | | loading (e.g., tissue strain, stress, strain rare, stress rate)in normal and low-g environments? | | | | | | | | | | | | | | | | | | | | | |
| | , | | 4 | | What are the bone and connective tissue markers | 5d3 2 | N | ဇ | - | - | ო | × | × | × | × | <u>^</u> | × _ | | N | | <u></u> | | <u>က်</u> | , (x | | |
| | | | | | of metabolism (protein synthesis, secteuril, and decradation)? How can bone marker data be used | | | | | - | | | | | | _ | | | | | | | | | | |
| | | | | | to investigate and predict regional changes in bone | | | | | | | | | | | - | | | | | | | | | | |
| | | | | | metabolism? | , | | | | _ | | | | ; | ; | | , | | | | - | • | 1 | | | _ |
| | | | | | What key elements of bone and connective tissue | 5d6 2 | ო | 7 | - | - | <u>ო</u> | × | × | × | × | _ | × | | _ | _ | | | _ | | | - |
| | | | | | structural assembly impact the biomechanical | | | | | _ | | | | | | _ | | _ | | | | | | | | |
| | | | | | properties? | | | | | | | | : | | ; | | | | | • | | | ١ | | | |
| | 2 • | | | | Are there specific load histories that affect the | 5d7 2 | N | N | <u> </u> | - | <u>ო</u> _ | × | <u>×</u> _ | <u>×</u> | × | × | × | | | | _ | | | | | |
| | | | | | macromolecular assembly of connective tissues? | | | | | | | | | | | _ | | | • | | , | | | c | | |
| | ٠ ٧ | | 4 | | What are specific signal transduction processes | 548 2 | 7 | 8 | - | - | <u>ო</u> _ | × | | × | × | | | _ | _ | _ | | | <u>`</u> | 0 | | |
| | | | | | relevant to the modulation of structural molecules | | | | | | - | | | | | | | | | | | | | | | |
| | | | | | during altered load histories? | | _ | | | | | | : | ; | ; | | ; | _ | | • | | _ | | α | | |
| | ۲, | က | 4 | | What are sensory inputs and coordination of | 662 2 | ო | ო | - | 7 | - | <u>×</u> _ | <u>×</u> _ | × | × | Κ_ | <u> </u> | - ' | _ | - | | | : | 5 | | |
| | | | | | muscular outcomes organized for generation of | | | | | - | _ | | | | | | | | | | | | | | | |
| | | | | | posture and locomotion before, during, and after | | | | | | | | | | | | | | _ | | | | | | | |
| | | | | | flight? | | | | | | | | | | | | ; | | | ` | | | 1 | 0 | | |
| | 2 | <u>ო</u> | _ | | What are the optimal countermeasures for motor | 6b3 | 2 | _ | - | 2 | 2 2 | × | <u>×</u> | × | × | <u>×</u> | × | | | | | _ | <u>:</u> | 0 | | |
| | | | | | readaptation to partial-g or 1-g after adaptation to | | | _ | | | | | | | | | | _ | _ | | | | | | | |
| | | | | | microgravity? | | | | | | | | | | : | | ; | | | | | • | 1 | a | | |
| | 2 • | | 4 | | What adaptive processes modify motor control | 6b5 | 2 | _ | - | N N | - | <u>×</u> | × | <u>×</u> | × | | <u>.</u> × | | _ | | | | _ | D | | |
| | | | | | systems? What is the dynamic range of adaptation | | | | | | | | | | | | | | _ | | | | _ | | | |
| | | | | | of motor responses in altered states of gravity? | | _ | 4 | | | \dashv | \dashv | ┩ | 4 | ╛ | | 1 | 1 | 1 | ┨ | \dashv | \dashv | 4 | | | 1 |

All Critical Questions Which Would Require Ground Based Research

| 5 | 18 | 8 | ਤਿ | S | C1 C2 C3 C4 C5 Critical Question | _ | | Ŀ | ٩ | Ŀ | ┢ | | | ŀ | | | L | L | r | - ⊩ | | - | | | | İ | |
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| ľ | †: | Ť | †. | | | #18 BD 7 | 5 | 2 | 2 | 4 | <u>ې</u> | <u>'</u> | 8 | 6 | - | = | 12 | 33 | 4 | 15 | 9 | 7 | 18 G | iroup | Group w/ other | other | Disc |
| | N | • | 4 | | What processes explain the attered perceptions of joint and body position in microgravity? | 605 | 7 | ო | 2 | 3 | 2 2 | × | × | × | | × | × | | | - | - | Ι <u>-</u> | | 80 | 60 | ļ | |
| | · 0 | | 4 | | If an on-board centrifuge is used as a countermeasure (physiological system | 662 | 2 | _ო_ | | 8 | | <u>×</u> | | × | × | | × | | | - | | | 4, | ν, | 7, 8 | | |
| | | | | | maintenance), will going from 1-g to microgravity cause repeated maladaptions? | | | | | | | | | | | | | | | | | | · | | | | |
| CI. | * | <u> </u> | 4 | | What are the joint effects of radiation and microgravity? | 811113 | 2 | | - | _ | 2 | <u>×</u> | × | × | × | × | × | | | | | | <u></u> | | | | |
| | | | | | How do neoplasms common to chronological aging relate to limitation of cell lifespan and susceptibility to abnormal growth regulation under altered gravitational fields? | | | | | | | | | | | | | | | - | | | | | | | |
| α | <u>ო</u> | | <u> </u> | | What is the role of gravity in the regulation of the distribution, composition, and pressure of | 8Vb2 2 | <u>~</u> | N | 8 | ~~ | 2 | <u>'</u> × | × | × | _×_ | × | × | | | _ | | | 4, | 10 | | | |
| | | | | | materization in trying systems from cells to complex organisms? How do these changes influence other homeostatic and regulatory mechanisms? | | | | | | , | | | | | | | | | | | | | | | | |
| - 2 | ო * « | | . | <u></u> | is musculoskeletal growth, development, and function compromised during spaceflight and can they readent upon return to Farth? The standing | 8VI1 2 | <u>က</u> | | - | | _ | _× | × | × | × | × | × | | - | | | | က် | 7, | 80 | | |
| | | | | | and functional systems that should be examined carefully are: (1) the postural muscles, (2) muscle spindles, (3) weight/load-bearing bones and joints, (4) intervertebral discs. (5) the architecture of | | | | | ··· | | | | | | | | | | | | | | | | | |
| | | | | | the connective tissues of the body and (6) musculoskeletal innervation. | | | | | | <u> </u> | | | | | | | | | | | | | | | | |
| Ν | <u>ო</u> | | | | What is the role of fluid redistribution in the response of the musculoskeletal system to altered gravity and how does gravity impact the | 8V14 2 | ~ | 2 | ~ | 2 | <u>ო</u> | _× | × | × | × | × | × | | | | - - | _ | νί | œ | | | |
| \dashv | 4 | \dashv | \dashv | | homeostasis of fluid compartments within tissues? | | | | | | _ | | | | | | | | | | | | | | | | · |

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All Critical Questions Which Would Require Ground Based Research

Table 3

| | | | | | | | | | | | | | | | ľ | ł | ł | ŀ | L | | | | | | | | Г |
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| 5 6 | 3 - | 5 | + | <u>' </u> | hale the musculoskeletal adaptation to | 8/19 | 2 | - | - | 1 2 | က | × | × | × | × | <u> </u> | × | | | _ | _ | - | 7, 3, | & | | | |
| ų | | | | | A same as those | | _ | | | | | | | | | | | _ | | | | | | | | | _ |
| | | | | , <u>u</u> | found in biomechanical unloading on Earth? | | | | | | | | | | | | | | | | | | | | , | | |
| 0 | • | | | _> | eletal | 8V110 | 2 | _ | | 1 2 | <u>ო</u> | × | × | × | × | <u>^</u> × | × | | - | | _ | _ | 7, 88 | | | | - |
| <u> </u> | | | | S) | system in response to changes in stresses, | | | | | | | | | | | | | | | | | | | | | | |
| | | | | S | strains, and strain rates? | • | | | | | | - | | | | | | | • | | 1 | , | | - | | | |
| Ŋ | • | | | <u></u> | der, species, | 8VI15 | 2 | _ | <u>. </u> | <u>-</u> | <u>ო</u> | × | <u>×</u> | × | × | <u>`</u> | × | | | | | | , , | | | | |
| | | | _ | S | strain (race), nutrition) modulate the | | | | | | | | | | | _ | _ | | | | | | | | | | |
| | | | | | musculoskeletal response to altered gravity? | | | | | | | | | | | | - ; | | | • | | , | _, | | | | |
| 2 | رن | 4 | | | What are the major human factors principles that | 1a3 | 3 | <u>¥</u> | ၉ | - | N | × | × | × | | Ė | × | | _ | | _ | | _ | | | | |
| | | | | 0 | govern optimal assignment of responsibilities | | | ** | | | | | | | | | | | | | | | | | | | |
| | | | | | between space crews and ground teams and among | | _ | | | | _ | | | | | | | | <u>.</u> | | | | | | | | _ |
| | | | | | Gew and team members? What ground-based | | | | | | | | | | | | | _ | | | | | | | | | _ |
| _ | | | _ | | organizations are required for effective support of | | | | | | | | | | | | | | | | | | | | | | |
| | | _ | | | flight crew performance on a Mars mission? | | | | | | | | | | | | | 4 | | | , | | _ | | | | |
| <u> </u> | • | | | | What are the critical elements and processes | 1a4 | 3 | <u>~</u> | က | 2 | - | × | × | × | | | × | | Ξ. | _ | <u></u> | | | | | | |
| 4 | | | | | and the decision making by profind teams and | | | _ | | - | | | | | | | | | | | | | | | | | |
| | | | | | INCOME IN CONTROL MANAGEMENT OF THE CONTROL OF THE | | | | | | | | | | | | _ | _ | | _ | _ | | | | | | _ |
| | | | | | space crews operating automotionary of in | | | | | | | | 1 | | | | | | | | | | | | | | _ |
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| 7 | د | 4 | | _ | What are the optimal communication procedures | 1a8 | <u>ო</u> | <u>\{ \} \</u> | 9 | N . | <u> </u> | <u><</u> | | <u><</u> | | | - | _ | | <u> </u> | _ | | | | | | |
| | | | | | for coordination among crew members and between | | | | | | | | | | | | | | | | | | | | | | |
| | <u>-</u> | | | | ground and space crews? | | | | | | | | | | | | ; | | | | • | • | ç | | | | _ |
| | • | | - | | What are the optimal designs for living/working | 1c2 | <u>ဗ</u> | ب | က | <u>-</u> | <u>-</u> | <u>×</u> | | <u>×</u> | | | × | _ | | N | | | 2 | | | | _ |
| | | | | | areas in spacecraft/habitats to maximize morale | | | _ | | | | | | | | | | _ | _ | | | | | | | | |
| | _ | | | | and performance? | | | | | | | | _ | | | | | | | | | | | | | | |
| ., | . 2 | | — | | What are the requirements for formatting, | 1d3 | <u>හ</u> | 3 | ო | 2 | 2 | <u>×</u> | | × | | | | | _ | | | | <u></u> | | | | |
| _ | | | _ | | distributing, managing, accessing, updating, and | | | | | | | | | | _ | | | | | | | | | | | | _ |
| | | | | | presentation of information for optimal individual | | | | | | | | | | | | | | | | | | | | | | _ |
| | | | | | and crew performance? What are the | | | | | | | | - | | | | | | | <u>-</u> | | | | | | | |
| | | | | | requirements for crew input to the data | | | | | | | | _ | | | | | _ | | | | | | | | | |
| | | | | | management system? | | | \dashv | \Box | | \dashv | \dashv | \dashv | \dashv | 4 | | | 1 | \dashv | 4 | 4 | 4 | | | | l | 1 |

All Critical Questions Which Would Require

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| What are the anthropometric requirements for work stations to accommodate individual team members to maximize performance? How can artificial intelligence systems be used to space flight? How can artificial intelligence systems be used to systems be used to support human decision-making in long-duration space flight? What are the mission specific design and protocol 1d10 3 2 1 3 1 2 1 X X X X X X 1 2 2 1 crew performance? What are the most effective schedules for work, 1f2 3 3 NR 3 2 1 2 X X X X X X X X X 1 1 1 1 1 1 1 1 | N | • | | | | What are the human factors issues in teleoperation? | 146 | 6 | - | | - | 7 | <u> -</u> | × | | +- | _ | × | , - | | , | 5 | | • | 7 , | | 0 |
| How can artificial intelligence systems be used to support human decision-making in long-duration space flight? What are the most effective schedules for work, loss of a crew performance? What are the most effective schedules for work, loss of a few included and team adaptation of the space of the support humans beformance and adaptation during long-duration exposure to space? What methods characterize the process of individual and team adaptation to stressors (e.g. isolation, confinement, and risk) inherent in space in case of loss of a crew member inflight, or loss of a family member or friend on earth? How is support human artification approach and adaptation approach and adaptation to stressors (e.g. isolation, confinement, and risk) inherent in space in case of loss of a crew member inflight, or loss | N | <u>ო</u> | | | | What are the anthropometric requirements for work stations to accommodate individual team members to maximize performance? | 148 | | | | N | 8 | _ | | | | | × | | | | | | | | | |
| What are the mission specific design and protocol requirements for telecommunications to optimize crew performance? What are the most effective schedules for work, rest and recreation exposure to space? What are the most effective schedules for work, rest and recreation exposure and sleep for enhanding human performance and adequation during long-duration exposure to space? How is workload optimized for various space Explorations? What methods characterize the process of individual and team adaptation to stressors (e.g. isolation, confinement, and risk) inherent in space flights What are effective protocols for sustaining crews in case of loss of a crew member inflight, or loss of a family member or triend on earth? | CV. | <u>ო</u> | | | | How can artificial intelligence systems be used to support human decision-making in long-duration space flight? | 149 | | | | -0 | 8 | _ | × | | | | × | - | | | | | - | | | |
| What are the most effective schedules for work, 1f2 3 3 NR 3 2 1 2 X X X X X X X X X X X X X X X X X | N | <u>ო</u> | | · | | What are the mission specific design and protocol requirements for telecommunications to optimize crew performance? | 1410 | | | ო | | 0 | - | | | | | × | | | | | | | | | |
| How is workload optimized for various space 116 3 2 1 3 1 2 1 X X X X X X X X X X X X X X X X X | N | • | | | | What are the most effective schedules for work, rest and recreation, exercise and sleep for enhancing human performance and adaptation during long-duration exposure to space? | | | | | N | + | | | | | | × | | - | - | | - | 4 | | | |
| What minimally intrusive hardware and software capabilities are best suited for obtaining performance data in flight? What methods characterize the process of individual and team adaptation to stressors (e.g. isolation, confinement, and risk) inherent in space flight? What are effective protocols for sustaining crews 1g5 3 2 NR 3 2 3 3 X X X X 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | | • | | | | How is workload optimized for various space explorations? | | | | ო | - | 8 | | | | | | × | | | | | | | | | |
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All Critical Questions Which Would Require Ground Based Research

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| | ≅ | ğ | sleep, sleep cycles, or the generation, expression (period, phase, amplitude and/or waveform), and | rai | and/or behavioral circadian rhythms? Of these | effects, which result from altered gravity and | which result from other environmental factors? | What are the effects of exercise on circadian | rhythms and sleep? What pharmacological and | nonpharmacological (e.g. light, exercise) agents | مّ ۔ | What are the effects of routine administration | pharmacological agents in space on circadian | rhythms and sleep? | What roles do age and gender play? Is there a | response of the circadian system to the space | environment? | Does the well documented decrease in red blood | cell mass termed "anemia of space flight" | represent a normal microgravity-associated | adaptive process (self-limiting) or a transient | response (self- correcting) to changes brought | about by various space-flight-related stimuli | (stressors)? |
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All Critical Questions Which Would Require Ground Based Research

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| | | | _ | mass during simulated and actual microgravity? | | | _ | _ | _ | <u> </u> | | | _ | _ | | | | | - | - | <u>`</u> - | ۸ 4 <u>.</u> | ŗ, | , o | | | |
| | | _ | _ | Should red cell mass be restored during space | | | | | | | | | _ | | _ | | | | | | _ | | | | | | |
| | | | _ | might? Are these acute or chronic changes and are | | | | | | | | | _ | | | | | | | | | | | | | | |
| | | | | they of sufficient magnitude or duration to pose an | | | - | | | | | _ | | | | | | | | _ | | | | | | | |
| | | | | unacceptable medical risk and warrant the | | | | | | | | | | | | | | | | | | | | | | | _ |
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| V | _ | 4 | _ | Is the basal metabolic rate and metabolic efficiency | 281 | , | <u>-</u> | 9 | _ | c | • | | _ | | | _ | | | | | - | _ | | | | | |
| | | _ | _ | altered during extended space flight? Are there | | | _ | | _ | ų. | 2 | <u>`</u> | <u><</u> < | <u>×</u> | | | | | <u> </u> | - | <u> </u> | 4 | ທີ | 7 | | | |
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| | | | - | Grianges in energy metabolism and storage in | | _ | | | | _ | | | _ | | | | | | | _ | _ | | | | | | _ |
| | | - | _ | space, especially in substrate utilization? | | | - | | | | | _ | | | | | | | _ | _ | | | | | | | _ |
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| | | | _ | methods and techniques for use during space flight | | _ | | | | | | | | | | | | | | <u> </u> | _ | 4 | | | | | |
| | | | | to monitor nutritional status? | | | | _ | | | | | | | | | | | _ | | | | | | | | |
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| | | | | inu ogen balance and changes in lean body mass | | | _ | _ | _ | | | _ | | _ | | _ | | | <u> </u> | <u> </u> | - | - | | | | | |
| | _ | _ | _ | incurred during space flight? What are the | | | - | _ | _ | | _ | - | | _ | | | | | _ | _ | | _ | | | | | |
| | _ | _ | | possible interventions including diatary | | _ | _ | | _ | | | | | | | | _ | | | | | _ | | | | | |
| | | _ | _ | attentions in protection and artificial | | _ | | _ | | | | | _ | _ | - | | | | | | | _ | | | | | |
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| | | | _ | Inutrients? What is the safe range of exogenous | | _ | _ | _ | | | | _ | _ | | _ | | | | | | | | | | | | |
| | | | | vitamin intake for long-term space flight? Are | | | | | | | | | | | | | _ | _ | | | | | | | | | |
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| | | | | digestive disturbances, such as the anorexia. | | _ | | _ | | | _ | _ | _ | _ | | | _ | | | | | | | | | | |
| | | | | nausea, and vomiting associated with space | - | | _ | _ | | | _ | | | | | | | | - | | | | | | | | |
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All Critical Questions Which Would Require Ground Based Research

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| tion Onestion | What is the time course and nature of body | composition change due to space flight? Do changes in body composition (age and gender) have an effect on crew health and performance? | What are the fluid and electrolyte regulating mechanisms underlying the cardiovascular responses to microgravity? | What are the mechanisms for the chronic adaptive shifts in fluid and electrolytes during space flight? | ability to respond to heat stress, electrolyte loading. EVA, and countermeasures? | What are the best methods to accurately measure fluid loss, fluid intake, plasma volume, | extracellular fluid, total body water, and interstitial volume in space flight? | What are the effects of circadian rhythm changes in space flight on the responsiveness of the fluid | and electrolyte system? What are the roles of renal blood supply and renal electrolyte handling in extracellular fluid volume | control during simulated and actual microgravity? What is the relationship between the cardiovascular adjustments to space flight and | those occurring in Earth-based models such as bedrest, immersion, and head-down tilt? Are the baroreflexes modified by space flight and how do these affect orthostatic tolerance? Are chemoreflexes and osmoreflexes modified by space flight and how do these affect orthostatic tolerance? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community Table 3

All Critical Questions Which Would Require Ground Based Research

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| C1 C2 C3 C4 C5 Critical Question | How are countermeasures to adverse | cardiovascular effects of long- duration space flight affected by changes in fluid distribution? | Are there appropriate animal and/or computer models for studying each functional element of cardiovascular adjustments to microgravity? | Are there changes in cardiac performance and contractile efficiency during long term exposure to microgravity? | Is pulmonary function altered in long-duration space flight at rest, exercise, or in a disease state? | What are the physiological similarities and differences of ground- based models of muscle atrophy and fiber transformation and | weightlessness-induced muscle atrophy and fiber transformation? How valid are ground-based models for studying the characteristics of space-flight-induced muscle changes? What are the molecular signals and mechanisms that are responsible for the control of muscle hypertrophy and atrophy, and what are the specific stimuli that are generated by exercise or disuse to signal increased or decreased protein accumulation in muscle collections. | ationship between of protein metabolism | What is the molecular basis for the effects of unloading on the susceptibility of muscle to injury or damage upon resuming normal weight-bearing states? |
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All Critical Questions Which Would Require Ground Based Research

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All Critical Questions Which Would Require Ground Based Research

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|) ng | 6a1 | | 6а3 | 6b1a | 6b4 | 6c2a | ŭ | 4 | |
| F | - | = | | | | to 6c | , ec3 | f 6c4 | |
| | | rtical | What are the neural (morphophysiological) and neuroendocrine bases for motion sickness? What changes in neurotransmitters, neuroendocrine, or neurohumoral release can be correlated with space motion sickness? | ij | What are the pharmacology, physiology, and output pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | | es in | What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory | į |
| | Are there changes in the processing of signals from the semicircular canals or addith organic | occur with adaptation? Do these changes take place within the vestibular nuclei, cerebellar structures or other related brainstem and cortic structures? What is the time course of such changes and do they correlate with space motion sickness? | What are the neural (morphophysiological) and neuroendocrine bases for motion sickness? What changes in neurotransmitters, neuroendocrine, or neurohumoral release can be correlated with space motion sickness? | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and out pathways that control the autonomic and endocri outputs characteristic of motion sickness? | What psychophysical correlates can best be used describe spatial orientation? | Does a change in vestibular input lead to changes visual and auditory localization and multisensory spatial orientation? | re n ar a | and visual inputs in determining orientation in a three-dimensional environment? How do these interactions change in altered gravity? |
| | sig | occur with adaptation? Do these changes tak place within the vestibular nuclei, cerebellar structures or other related brainstem and costructures? What is the time course of such changes and do they correlate with space moisickness? | ss? doci | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordinwith varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and pathways that control the autonomic and en outputs characteristic of motion sickness? | eq : | cha Itise | is a igula | orientation in a How do these ravity? |
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| ij | # E | occur with place with structures structures changes a sickness? | What are the neu neuroendocrine ba changes in neuro neurohumoral rele motion sickness? | How does gaze stabilization change gravitational states? What are the characteristics of gaze and eye-heawith varying visual, vestibular, and somatosensory inputs? | at e hwa put: | What psychophysical correlate describe spatial orientation? | Does a change in ve visual and auditory spatial orientation? | at gr | visi e-di raci |
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All Critical Questions Which Would Require Ground Based Research

| 7 | 2 | S | کا | 15 | Co Ca CA C5 Critical Question | Quest# C | 1 | 2 | 3 | 4 | 5 6 | 2 | 8 | <u></u> | 100 | Ξ | 12 | 131 | 4 1 | 5 1 | 6 17 | 18 | _ | 9 | Group w/ other | 1 1 | Disc |
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| _ | 'n | က | | | How does gravity affect the regulation of | 8Vb1 3 | <u>-</u> | 7 | _ | - | 3 | <u>×</u> ~ | <u>×</u> | × | × | × | × | | | | - | <u>-</u> | <u>რ</u> | _ | | | |
| | | | | | metabolism,? Basal metabolic rate? Energy, | | | | | | | | | | | | | | _ | | | | | | | | _ |
| | | | | | metabolism, storage and substrate utilization? | | | | | | | | | | | | | | _ | | | | | | | | |
| | | | | | Body composition (fat and protein metabolism)? | | | | | | _ | _ | | | _ | | | _ | | _ | | , | _ | | | | |
| | ٠. | | | | How does microgravity affect the function | 8Vb4 3 | <u>-</u> | _ | N | رز ص | 8 | × ເ | <u>×</u> | × | × | _ | × | | | _ | | _ | 4 | | | | |
| | | | _ | | including feeding behaviors of gastrointestinal | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | function? | | _ | | | | | | | | | | | _ | _ | | | | | | | | |
| | ٥. | | 4 | | How does gravity interact with other | 8Vb10 | 3 | - | - | <u>-</u> | 2 | × ε | × | × | × | × | × | | _ | - | _ | _ | | | | | |
| | | | | | environmental factors to control regulatory | | | _ | | | | | | | | | | | | | | | | | | | |
| | | | | | physiology and behavior? | | | _ | | _ | | | | | _ | | | | | | | | (| | | | |
| | , | ٣ | | | What are the transduction mechanisms that couple | 8V17 | 3 | <i>~</i> | ٠. | ٠ | <u>ن.</u> | <u>×</u> | × | <u>×</u> | × | | × | | _ | - | _ | _ | က် | 7, 88 | | | |
| | J | | | | mechanical stress to musculoskeletal mass and | | | | | | | | | | _ | | | _ | | | | | | | | | |
| | | | | _ | strength? What are the activation and force | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | | | development processes of muscle and bone cells? | | | | | | | | | | | | | | | | | | | | | | |
| | ٠ | | | | Do we need artificial gravity countermeasures to | 12.1 | 3 | _ | 2 | _ | - | ^ | × | × | × | × | × | | <u> </u> | - | | _ | c, | ა დ | | | |
| | | _ | | | protect from physiological deconditioning of a | | | | | | | <u>'</u> | | | | | | | _ | | - | | | | | | |
| | | | | | mission to Mars? | | | | | | | | | | | | | _ | - | _ | | | | | | | |
| | , | | | | How should artificial gravity be applied in terms of | 12 2 | 3 | က | 0 | - | <u> </u> | <u> </u> | × × | × | × | × | × | _ | • | <u>-2</u> | - | _ | oj. | က် (၁ | | | |
| | | | | | g-load, rotation rate, and intermittent versus | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | continuous exposure? | | | | | | | - | | | | | | | | | | | | | | | |
| | ٠, | | | | What models can developed to describe the effects | 1113 | 4 | Ž | 2 | 2 | _ | ^ | × | × | | | × | | | - | | _ | 4 | | | | |
| | <u></u> | | | - | of fundamental behavioral stressers on mission | | | | | | | | _ | | | | | | | | | | | | | | |
| | | | | | performance? | | | | | | | | | | | | | | _ | | 1 | | | | | | |
| _ | * N | * | 4 | | What are the effects of intermittent and variable | 2a2 | 4 | N | က | Ø | N. | <u>ი</u> | × × | × | <u>×</u> | ×_ | × | | | <u>-</u> | | | Ņ | o O | _ | | |
| | | | _ | | gravity fields on circadian rhythms, and how does | | | | | | | _ | | | | | | | | | | _ | | | | | |
| | | | | | this affect the use of artificial gravity as a | | | | | | | _ | - | | | | | | | | | | | | | | |
| | | | | | countermeasure to microgravity? | | \dashv | \dashv | \Box | | | 1 | \dashv | \dashv | \dashv | \dashv | 4 | | | 1 | ┪ | ┥ | \dashv | Ì | | | |

All Critical Questions Which Would Require Ground Based Research

| 2 8 | <u>ප</u> | | C1 C2 C3 C4 C5 Critical Question | Quest# | CT | 1 2 | 2 3 | 4 | 2 | 9 | 7 | 8 | 6 | 10 | F | 2 | 3-1 | 14 | 516 | 6 17 | 18 | | ٩ | Group w/ other | | Disc |
|---|--|---|---|----------|---------|----------|----------|----|---|--------|---|-------------|------------|---------|----------|----------|-----|----|---------------|------|-------------|---------------|----------|----------------|---|-------------|
| What are the studying the human circac | What are the studying the human circac | What are the studying the human circad | What are the appropriate ground-based analogs for studying the effects of extreme environments on human circadian rhythms? | 2a7 | 4 | 2 | | 8 | 0 | - | × | | × | | × | <u> </u> | | - | 0 | - | - | 9, | 4, 5, | 6, 7 | 1 | |
| 4 What are ap simulating th | What are ap simulating the | What are ap simulating th | What are appropriate research models for simulating the effects of the space environment? | 2a8 | 4 | ь — | <u>ო</u> | 8 | 8 | _ | × | | - | ******* | | | | | | _ | | ₹ | | | | |
| What are the effect physical-chemical are space-flight-induced rhythms and sleep? | What are the physical-che space-flight-inthms and | What are the physical-che space-flight-frythms and | What are the effects of non-gravity-related physical-chemical and psychological space-flight-induced stressors on circadian rhythms and sleep? | 2a9 | 4 | 8 | <u>ო</u> | N | | ო | × | × | × | × | × | | | | *- | | | က <u>်</u> | 4, R, | 6, 7 | | |
| What are the effects circadian rhythms? | What are the circadian in | What are the circadian | What are the effects of cephalad fluid shifts on circadian rhythms? | 2a12 | 4 | <u>ო</u> | ~ | Ċ | - | က | × | × | × | × | <u>×</u> | | | | | - | | · 4. | | | | |
| What are the rela associated with s and magnitude of immune function? | What are the associated and magnitud immune fur | What are the associated and magnitud immune fur | What are the relationships between the stressors associated with space flight; the source, duration and magnitude of the stressor; and decreased immune function? | 245 | 4 | 01 | | Ν | N | e e | × | × | ` × | | <u>×</u> | | | | - | | | . , 6, | o | • | | |
| — Are there countermeasur their effects? | Are ther countermeas their effects | Are ther countermeas Their effects | — Are there effective operational procedures or countermeasures to counteract the stressors or their effects? | | | | | | | | | | | | | | | | ** | | | | | | | |
| Are there te computer mo effects of s to the immur | Are there te computer me effects of s to the immur | Are there te computer me effects of s to the immur | Are there terrestrial (1 g) human, animal and/or computer models that simulate or reproduce the effects of space flight/microgravity with regard to the immune system in space? | 2d6 4 | <u></u> | | | α | Ν | ო | × | × | | | | | | N | - | - | - | ₹ | | | | |
| What are the e turnover during requirements? | What are the turnover during requirement | What are the turnover during requirement | ffect of changes in cell and nutrient space flight on nutritional | 2e2a 4 | N | | ~ | - | N | m | × | × | _ <u>×</u> | | | · | | - | - | - | - | 4 | | | | |
| What are the countermeas | What are the | What are the countermeas | What are the effects of prescribed countermeasures on thermoregulation? | 2g4 4 | | | Ν. | Ν, | 8 | n | × | × | × | | × | | | - | | | - | 4, | | | | |

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All Critical Questions Which Would Require Ground Based Research

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| 102 | 3 | 8 | C2 C3 C4 C5 Critical Question | Quest# | 5 | 2 | <u> </u> | 4 | <u>.</u> | | | _ | 2 | _ | • | + | - | · · | 4 | , | | | | | |
| , | 6 | | Are there appropriate animal and/or computer | 3b7 | 4 | 3 4 | - | 7 | <u>-</u> | <u>×</u> | <u>×</u> | <u>×</u> | × | <u>×_</u> | × | | | _ | | | ი | | | | |
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| | | | pulmonary adjustments to microgravity? What is | | _ | _ | | | | | | _ | | | | | - | | | | | | | | |
| | | | the relationship, if any, between the pulmonary | | | | | | | | | | | | | _ | | | | | | | | | |
| | | | adjustments to space flight and those occurring in | | | | | | | | | | | | | | _ | | | | | | | | |
| | | | Earth-based models such as bedrest, immersion, | | | | | | | _ | | | | | | | | | | | | | | | |
| | | | and head-down tilt? | • | | | | | | _ | | | _ | > | > | | | | - | - | α α | | | | |
| 9 | • | 4 | What is the role of specific hormones, | 5 b5 | 4 | 3 | 2 | _ | | ი | <u>×</u> × | <u><_</u> | <u> </u> | <u><</u> | <u><</u> | | | _ | _ | | | | | | |
| 1 | | | oharmacologic agents, and growth factors in | | | | | | | | | | | | | | | _ | | | | | | | |
| | | | regulating protein and gene expression in response | | | | | | | | _ | | | | , | | | | _ | | | | | | |
| _ | | | to unloading? | | | | | | | * | | | | | ; | | | | <u>, </u> | <u> </u> | | Ç | | | |
| • | • | | circuitry and signals in the vestibular | 6a2a | 4 | 3 4 | 7 | _ | _ | N | ≏ × | × × | × | × | × | | _ | <u> </u> | _ | <u> </u> | - <u>`</u> | 5 | | | |
| <u>v</u> | <u> </u> | ŧ. | Wild alough that constate a | | | | | | | | | - | | | | | _ | _ | _ | | | | | | _ |
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| | | _ | gravito-inertial frame of reference? What are the | | | | _ | | | | _ | | _ | _ | | | | | _ | | | | | | _ |
| | | _ | roles of the different regions of the cerebellum? | | | | | | | | | | | <u> </u> | > | | | <u> </u> | _ | | 8 | 10 | | | _ |
| ~ | | | What is the distribution of receptors for | 6a6 | 4 | ് | э 5 | 2 | _ | 2 | × | <u>×</u> × | <u><_</u> | <u> </u> | <u><</u> | | | <u>-</u> | | | | | | | |
| <u> </u> | | | anti-motion sickness drugs in central vestibular | | | | | | | | | _ | | | | | | | | | | | | | |
| | | | pathways? | | | _ | _ | | | | | | | | _> | | | | | | α | 10 | | | - |
| 0 | • | 4 | What is the most appropriate three-dimensional | 6b1b | 4 | ი | 2 | 8 | _ | N | × | <u>× </u> | | <u> </u> | <u> </u> | | | <u> </u> | _ | _ | | | | | |
| <u> </u> | | | model of the angular and linear VOR and of central | | | | | | | | | | | _ | | | | | _ | | | | | | |
| | | | vestibular processing that will account for | | | | | | | | | _ | | | | | | | | | | | | | |
| | | | alterations in eye movements in microgravity? | | | | | | | _ | | | _ | | _; | _ | | - | | | ~ | 4 | | | - |
| 0 | • | 4 | What models of sensory-motor transformation can | (Pp.) | 4 | 7 | - | <u>e</u> | _ | 8 | × | <u>` </u> | <u> </u> | <u> </u> | <u><_</u> | | | <u> </u> | | | | | | | |
| 1 | | _ | be used to predict motor behavior best in altered | | | | _ | _ | | | | | | _ | | | | _ | | | | | | | _ |
| - | | | gravitational states? | | _ | | ┪ | \dashv | 4 | | | 7 | \dashv | \dashv | 4 | |] | 1 | ┨ | 4 | 1 | | | | 7 |

All Critical Questions Which Would Require Ground Based Research

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| | 200 | How are the following cell functions influenced by gravity and/or affected by microgravity: the expression and regulation of genetic information; cell division; cell differentiation; signal transduction, including signal-membrane dynamics; intracduction, including signal-membrane dynamics; intracellular transport; secretion; alternate pathway regulation; and cell-to-cell communication? The importance of selecting cells and cell lines that can provide interpretable results bearing on precise questions cannot be overemphasized. How will altered gravitational fields and vectors change the information content of the three-dimensional microenvironment of the cells (stroma and matrix connections)? How does microgravity affect these signals under both homeostasis and challenge? Representative challenges would be wounding of dermal fibroblasts and keratinocytes (or epidermal/dermal wounding in vivo), differentiation of microvessel endothelial cells in vitro (or growth of the microvasculature in vivo, particularly following wounding or tumor implantation), and application of stress to active osteoblasts (or bones in vivo). | How long can single cells cope with changes in gravitational force without adverse results? Do these effects persist after return to unit gravity? |
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All Critical Questions Which Would Require Ground Based Research

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| ' ' ' ' | 2 5 | , 3 6 | [| uctural and morphometric alterations will | 81118 | - | - | - | 2 | 3 | × | × | × | | × | | | - | - | - | ώ | ω, | _ | | |
| | | | | occur in the extracellular matrix, the connective tissue, and the musculoskeletal systems in long | | | | | | | | | | | | | | | | <u> </u> | | | | | |
| | | | | Term spaceling in the space of How will this result in attered differentiation of | | | | | | | | | | | | | | | | | | | | | |
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| • | . 2 | | | _ | 8IV61 4 | 7 | <u> </u> | <u>. </u> | - | <u>. </u> | < | | <u>< </u> | | | | , | <u> </u> | <u> </u> | | | | | | |
| | | | -: | cells transduce acceleratory information, amplity | | | | | | _ | | | | | | | | _ | _ | | | | | | |
| | | | | it and bring about signal transmission? Is there a | | | | | | | | _ | | | | | | | | | | | | | |
| | • | , | | fundamental mechanism that is true across the | | | | | | | | | | | | | | | | | | | | | |
| | _ | | | animal kingdom? | | | | | | | | | | | | | | | | | 0 | | | | |
| | ; | က | | What is the role of gravity on sensory thresholds 8 | 8Vb5 4 | _ | <u>-</u> | 2 | 8 | က | × | × | × × | | <u>×</u> | | | _ | - | _ | 0 | | | | |
| | | | | (audition, visual, taste, pain)? How do endocrine, | | | | | | | | | _ | | | | | | - | | | | | | |
| - | | | | neurohumoral, and metabolic mechanisms influence | | | | | | | | | | - | | | | _ | | | | | | | _ |
| | | _ | _ | this effect? | | | | | | | | | _ | | | | | | | | | | | | |
| | 2 | 3 | | What role do endocrine and neural systems play in 8' | 8Vb7 4 | _ | _ | 2 | 8 | က | × | × | × | × | × | | | - | <u>-</u> | _ | <u> </u> | | | | |
| | | | | controlling/modifying adaptation to gravity? | | | | | | | | | | | | | | | | | | | | | |
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| | | | | subcellular mechanisms involved in adaptation to | | _ | | _ | | | | | | | | | | | | | | | | | _ |
| | | | | aftered gravity especially bioenergetics and | | | | | | | | | | | | | | | | | | | | | |
| | | | | associated processes and cell-to-cell interactions? | | | | | | | | | | | ; | | | , | _ <u>`</u> | <u> </u> | | | | | |
| | 2 | က | | What are the biochemical pathways responsible for 8VI6 | VI6 4 | _ | Ξ | - | <u>~</u> | က | × | × | × | × | <u>×</u> | | | _ | _ | | <u> </u> | | | | |
| | | | | synthesis, secretion, assembly, distribution, and | | | | _ | _ | | | | | | | | | | | | | | | | |
| | | | | degradation of structural and functional proteins in | | | | | | | | | | | _ | _ | | | | | | | | | _ |
| | | | | muscle in response to altered gravity? | | | | | | | | | | | | | _ | | | | | | | | _ |
| | ~ | * E | 4 | ndocrine | 261 1 | ო | 5 | 2 | 2 | က | × | × | × | × × | <u>×</u> _ | | | - | - | | <u>က်</u> | 4. | o, o | | |
| _ | | | | changes on the function of other homeostatic | | | | | | | _ | | | | | | | | | | _ | | | | |
| | | | | systems (e.g. cardiovascular, central nervous | | | | | | | | _ | | | _ | | | | | | | | | | |
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| | | | | reproductive system, gastrointestinal system, and | | | | | | | | | | | | | | | | _ | _ | | | | _ |
| | _ | | | energy metabolism)? | | _ | | | | \dashv | 4 | | | 1 | \dashv | 4 | ╝ | | | ┪ | ┨ | | | | 7 |

All Critical Questions Which Would Require Ground Based Research

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| 1 | Question | | to 3a3 is levels of surface he if these | ong-term space flight, are there delayed 3a12 at consequences, either beneficial or a corollary, are there appropriate measures that should be applied both term (hours to days) and long-term years) after flight? | rocedures should be 3b3 r resuscitation of 3ss of pressure in cardiopulmonary thesia? | /ent 4c2 crew risk? | | |
| 1 | Question | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | 3a3 | /ed 3a12 | 3b3 | 4c2 | 4c3 | 4c9 |
| 1 | Question | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these | Following long-term space flight, are there delayed 3a12 or persistent consequences, either beneficial or harmful? As a corollary, are there appropriate rehabilitative measures that should be applied both in the near-term (hours to days) and long-term (months to years) after flight? | 3b3 | 4c2 | 4c3 | 4c9 |
| 1 | Question | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to satravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? | Following long-term space flight, are there delayed 3a12 or persistent consequences, either beneficial or harmful? As a corollary, are there appropriate rehabilitative measures that should be applied both in the near-term (hours to days) and long-term (months to years) after flight? | Which pulmonary life support procedures should be 3b3 used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? | What procedures and approaches prevent decompression sickness or minimize crew risk? | 4c3 | What are the risks for bubble formation and clinical 4c9 decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? |
| | C4 C5 Critical Question | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these | Following long-term space flight, are there delayed 3a12 or persistent consequences, either beneficial or harmful? As a corollary, are there appropriate rehabilitative measures that should be applied both in the near-term (hours to days) and long-term (months to years) after flight? | Which pulmonary life support procedures should be 3b3 used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? | What procedures and approaches prevent decompression sickness or minimize crew risk? | Treatment of medical problems of spacecraft inner 4c3 temperature, and adverse effects of the gaseous environment? | What are the risks for bubble formation and clinical 4c9 decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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| Critical Question | 4 Does the atrophy from unloading make muscle, 5a9 1 2 | tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | 4 What potential risks does bone loss present to the 5c4 1 3 | development of bone fractures, hypercalcemia, metastatic calcification, and renal stone formation? | 5 How are risks associated with acute exposure to 7g6 1 2 space radiation to be managed medically? | What is the nature of space flight-induced changes 2e14 2 3 in effect of vasoactive drugs? | What is the nature of space flight-induced effect of 2e15 2 3 pharmocokinetics of drugs? | What are the effects of space flight and/or EVA on 2g1 2 2 thermoregulation processes and heat exchange? | There is an increase in cardiac arrhythmias 3a6 2 3 associated with space flight and, if so, what are the specific mechanisms responsible for them? | Does the extent of adaptation affect postflight 3a9 2 3 orthostatic tolerance? | Since microgravity alters blood pressures and 3a13 2 2 flows to some tissues, what are the structural and functional consequence with long direction flights? | What is the effect of long-duration space flights on 4b3 2 3 the human immune system? (Reg. Physiol see p. 6) | How completely and how well does injured muscle 5a10 2 2 repair in microgravity? |
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Table 3

All Critical Questions Which Would Require Ground Based Research

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| | | № | female crewmembers be managed to minimize the | risk of pregnancy, osteoporosis, and hemorrhage | from ruptured follicles during ovulation? What is | the role of gravity in developmental biology? | Does the developmental ontogeny of anima | raised through more than one life cycle under | changed gravity field differ from the 1-g classical | pattern? Does this altered pattern reside in the | genome, or is it relayed from hormonal and | stromal interactions? | - Are there critical windows of susceptibility | developmental processes, or is development | affected in a gradient? | - If gravity-related effects exist, can they | reversed in the short- or long-term? | > | dys-synchrony (temporal or hormonal) during | development? |
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| used in space? Which methods of fing drugs are the most effective in a predictable response during space ing drugs are the most effective in a predictable response during space se flight alter gastrointestinal function, he absorption of essential nutrients and ning of gut flora? What are the effects light on liver function? Are the effects of Are they reversible? The time course and magnitude of fluid changes in fluid compartment volumes limatization to hypogravity and during 1 g after flight? The time course and magnitude of the atrine course and magnitude of the autiliersis, and kaliuresis resulting from to hypogravity? Ironment of microgravity, does the sedimentation cause deeper penetration particles in the lung? In the spacecraft nt, what are the aerosol concentrations, in profiles, and bacterial lons? Do these factors constitute a and? The mechanisms inducing the acute loss of electrolytes in microgravity? | 0 | 294 | 201 | 2f1 | 2f6 | 362 | 3Vb3 | 217 |
| 20 2 20 3 3 * 4 4 4 4 5 * 5 * 5 * 5 * 6 * 6 * 7 * 8 * 9 * 10 * | 1 1 | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space flight? | Does space flight alter gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | What are the time course and magnitude of fluid shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during return to 1 g after flight? | What are the time course and magnitude of the diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations, particle size profiles, and bacterial contaminations? Do these factors constitute a health hazard? | What is the role of gravity on thirst and feeding behaviors (appetite, taste preference, and thresholds)? | |
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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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All Critical Questions Which Would Require Ground Based Research

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| ₹ S | સ I | - | C4 C5 Critical Question | | | 4 | , | J | \top | Ť | | ┪ | <u>:</u> | <u>: </u> | 1 | 7 | 十 | | | + | + | | | |
| . 4 | | | For the well documented changes in calcium metabolism associated with space flight, what are the direct and indirect consequences for electrical, mechanical, and vascular events in the heart? | 3a20 3 | ო | <u>ب</u> | ო | ო | - | × ~ | × | × | × | | | | α | - | | - | N | | | |
| 4 , | | | ease e e | 395 | ** | 8 | ო | - | N | × | × | × | × | | | | - CO | 2 | - | - | N | | | |
| | | | In terms of the fluxes of matter and energy that maintain disequilibrium conditions, what universal metrics can be developed for assessing the potential of different microenvironments to support the origin and evolution of life? | 1161 3 | 8 | <u>-</u> | ٠. | ₩- | ო | <u>^</u> | × | × | | | | | | Cl Cl | _ | | | 13, 14 | | |
| | | | What bounds do the energetics and dynamics of accretion and core formation place on the time when surface temperatures became suitable for the occurrence of liquid water? | 1162 3 | <u>e</u> | ın | <u>٠</u> | - | ო | <u>^</u> | × | | | | | × | | 8 | | | ~ 1 | 13, 14 4. | 4 | |
| * | | | What fluxes of intact organic compounds could have 11b3 been supplied to the Earth's atmosphere and surface waters by accretion of cometary or carbonaceous chondritic material? | 11b3 3 | <u>e</u> | <u></u> | N | | V | - | × | <u>×</u> | | | | | | | - | | _ | •0 | | |
| . 4 | | | What geological settings were conducive to the origin of life? | 1164 3 | - 2 | - | <i>~</i> | ** | ၉ | _ | × | | | | | × | | N | | _ | | | <u>4</u> ; | |
| | | - | What were the earliest products of the interaction of liquid water or atmospheric gasses or both with crustal rocks? | 1165 | <u>ო</u> | 4 | <u>٠</u> | - | | + | × | | | <u> </u> | | × | | | | | | | * ; | |
| 4 | | - | What minerals were available as potential chemical catalysts in the boundary regions? | 11b6 3 | <u>~</u> | <u>*</u> | <u>د-</u> | - | - | _ | × | | | | | × | | 2 | - | | | 2, 1 | 4 | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality

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All Critical Questions Which Would Require Ground Based Research

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|---|---|-----|---|--|--------|--------------|---|---------------|-------------|---|---|---|---|---|---|----------|------------|-------------|----|----------|--------------|--------------|----------|-----|---------|-----|
| ਲ | ខ | ঠ | | C5 Critical Question | Quest# | [| | <u>က</u> | 4 | 2 | ٥ | _ | 8 | 6 | = | | 7 | 5 - 4 | 2 | <u> </u> | = | <u></u> | Group w/ | - 1 | oniei C | 28 |
| | | . 4 | - | What are the biochemical and genetic properties of the universal ancestor of all life and from these | 1104 | <u>е</u> | | <i>د.</i> | | ო | _ | × | | | | | <u>×</u> _ | | 7 | - | - | - | 13, 1 | 4 | | - |
| | | | | properties the characteristics of its environment? | | | | | | | | | | | | | | | | | | | | | | |
| | | 4 | • | What are the simplest biochemical mechanisms and | 11c7 | 6 | 2 | <u>ن</u> خ | | ო | _ | × | | | | | | | N | - | - | _ | რ | 4 | | |
| | | | | structures that can carry out the various necessary functions of a living system? | | | | | | | | | | | | | | | | | | | | | | |
| | | 4 | | What is the correlation between the historical | 11d1 | <u>ب</u> | 8 | <u>ن</u> | _ | က | _ | × | | | | | × | | α_ | _ | - | _ | | 4 | | |
| | | | | pattern of biological evolution among complex | | | | | | | | | | | | | | | | | | | | | | |
| | | | | fossil organisms and geological record of environmental change? | | | | | | | | | | | | | | | | | | | | | | |
| | | . 4 | • | What is the history of effects on biological | 1142 | <u>ო</u> | 4 | 9 | | | _ | × | - | | | <u>×</u> | × | | 8 | _ | | - | € | 14 | | |
| - | | | - | evolution that have been exerted by | | | | | | | | | | | | _ | | | | | | | | | | |
| | | | | extraterrestrial phenomena? | | | | | | - | | | | | | - | | | | | | | | | | |
| | | 4 | • | The highest priority in the category requiring | 11415 | ю г | 4 | 2 | _ | | _ | × | | | | | × | | 8 | _ | _ | _ | <u>ლ</u> | 14 | | |
| | | | | flight missions is accorded to studies of Mars. | | | | - | _ | | | | | | | | | | | | | | | | | |
| | | | | Conduct chemical, isotopic, mineralogical, | | | | | _ | | | | | | | | | | | | | | | | | |
| | | | | sedimentological, and paleontological studies of | | | | | | | | | | | | | | | | | | - | | | | |
| | | | | Martian surface materials at sites where there is | | | | | | | | | | | | | | | | | | | | | | |
| | | | | evidence of hydrologic activity in any early | | | | | | | | | | | | | | | | | | | | | | |
| | | | | clement epoch, through in situ determinations and | | | | | | | | _ | | | | | | _ | | | | | | | | - |
| | | | | through analysis of returned samples; of primary | | | | | | _ | | | | | | | | | | | | | | | | |
| | | | | interest are sites in the channel networks and | | | | | | | | | | | | | | | | | | | | | | |
| | | | | outflow plains; highest priority is assigned to sites | | | | | | | | | | | | | | | | | | | | | | |
| | | | | in which there is evidence suggestive of water-fain | | | | - | | | | _ | | | | | | | | | | | | | | |
| | | | | sediments of the floors of canyons as in the Valles | | | _ | | | | | | | | | | | | | | | | | | | |
| | | | | Marineris syste, particularly Hebes and Candor | | | | | | | | | | | | | | | | | | | | | | |
| | | | | chasmata, and | | | | | | | | | | | | | | | - | | | | | | | |
| | | | | - Reconstruct the history of liquid water and its | | | | | | | | | | | | | - | | | | | | | | | |
| | | | | interactions with surface materials on Mars | | | | | | | | | | | | - | | | | | | | | | | |
| | | | | through photogeologic studies, space- based | | | | | _ | _ | | | | | | _ | | | | | | | | | | |
| | | | | spectral reflectivity measurements, in situ | | | | | | | | | | | | | | | | | | | | | | |
| | | _ | | measurements, and analysis of returned samples? | | | | | | | | | | | | | | _ | | | | | | | | |

Table 3

All Critical Questions Which Would Require Ground Based Research

| | | I | F | | | | | | | i | | | | | | | | | | | | | | | | | |
|--------|-------|--------------|--------------|---|--------|---------|---------------|----------|----------|--------------|----------|---|----------|----------|-----|---------------------------------------|----|----|----|-----|--------------|--------------|--------------|--------|----------------|---------|----------|
| წ ნ | C5 C3 | 8 | 4 | C5 Critical Question | Quest# | ı o | 1 | 2 | 3 4 | 2 1 | 9 | 4 | <u> </u> | ್ರಿ | - 2 | 듣 | 12 | 13 | 14 | 15 | 16 | [- | 18 | | Group w/ other | er Disc | <u> </u> |
| | | 4 | • | Look for extant life (does it exist?) on Mars - Microenvironments exist? - Life there? | 11d19 | 6 | 4 | 80 | ç. | _ | - | × | | | | <u> </u> | | × | | N | - | - | 1 | 13, 14 | 4 | | |
| | | 4 | , | What are the acute and long-term effects of the space environment on sleep architecture, quantity, and quality? | 1114 | 4 | - | <u>e</u> | 8 | - | 0 | × | × | × | | | × | | | - | +- | - | - | 4 | | | |
| 8 | က | 4 | | What are the mechanisms regulating thirst and electrolyte appetite during space flight? | 2f9 | 4 | 2 | - 2 | 2 | 21 | ო | × | × | <u>×</u> | × | | × | | | | - | _ | - | | | | · |
| | | 4 | * | What, if any, are the cardiovascular morphological changes associated with acute or long-term exposure to space flight (e.g., effects of microgravity, radiation, or environmental hazards | 3a15 | 4 | භ <u>භ</u> | က | <u>8</u> | | | × | × | | | | | | | α | +- | - | - | | | | |
| | | 4 | • | in the spacecraft)? Does atrophy of smooth muscle in the leg vasculature occur during long-term space flight? How are vascular endothelial structure and | 3a16 | 4 | 3 | <u>ග</u> | | | | × | × | | | | | | | | - | _ | +- | | | | |
| | ···· | . 4 | • | function alfered by such exposure and what are the consequences? What is the nature of the interplay between hemodynamic and electrophysiological responses to space flight and how much of this is reflex | 3a17 | 4 | 3 | <u></u> | <u> </u> | - | - | × | × | | | | | | | - 2 | - | - | - | | | | |
| | | 4 | * | Are there cellular and subcellular changes in function in the heart? Are there changes in myocardial contractile proteins? Is there a change in excitation-contraction coupling mechanisms induced by space flight? | 3a28 | . 4 | <u>e</u> | <u>ო</u> | - | ro e | _ ღ | × | × | × | × | · · · · · · · · · · · · · · · · · · · | | | | CV. | - | - | - | ις | | | |
| | | | * | What are the uses of microgravity for better understanding of cardiovascular function on Earth? | 3a29 | 4 | <u>2</u> | <u>e</u> | Æ | <u>£</u> | <u>£</u> | × | × | | | × | × | | | | _ | | - | | | | |
| | · | . | | What are effects of weight bearing on development? | 5a11 4 | 4 | ო | <u>ო</u> | | - | က | × | × | × | × | × | × | | | _ | — | - | - | | | | |
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Table

All Critical Questions Which Would Require Ground Based Research

| 5 | 12/2 | B S | N X | 105 | C1 C2 C3 C4 C5 Critical Question | Quest# | <u>c.1</u> | 2 | 6 | 4 | 2 | 9 | 7 8 | 6 | <u> </u> | 0 | 1 12 | 2 13 | 14 | 15 | 16 | 17 | 18 | Jo. | Group w/ | other | 1 1 | Disc |
|------|----------|--------|--------|-----|--|----------|------------|----------|---|---|--------------|---|-----|----------|----------------|---|------------|------|----|----|--------------|--------------|--------------|---------|----------|-------|-----|------|
| | - | 4- | 4 | | What is the role of thalamo-cortical systems in | 6a2b 4 | 4 | - | 8 | 2 | - | 2 | × | × | × | | | | | - | + | _ | - | 8, 10 | 0 | | | |
| 8 | <u> </u> | 4 | * | * | What neuronal models can be used to understand central processing and adaptation in altered pravitational states? | 6a4 | -4 -ε | ო | N | N | | N | × | × | × | × | × | | | - | - | - | - | დ დ | | | | |
| CV . | رة ق | 4 | • | • | At what sites do signals from the different receptors involved in gaze, body orientation, posture and motion converge? What are the characteristics of this convergence? | 6a5 4 | 4 ε | N | ღ | 0 | + | 8 | × | × × | <u>×</u> | × | × | | | - | - | - | - | က် ထ | | | | |
| | ო | | 4 | * | Does altered gravity lead to changes in neural control of biological rhythms, such as sleep, and temperature? | 6a7 4 | φ Θ | <u>ν</u> | N | N | - | 8 | × | × | <u>×</u> | | × | | | - | _ | - | - | ώ, Ω | | | | |
| | ო | 4 | • | | What changes are produced in the visual system by altered states of gravity? | 6a8 4 | 4 8 | - 2 | 2 | ო | _ | N | × | × | <u>×</u> | | <u>×</u> _ | | | _ | - | - | _ | တ က် | | | | |
| N | ო ი | | 4 | * | What are the psychophysical correlates and neural basis for perception of motion? | 6c1 4 | 4 © | ις. | 8 | ო | Ψ. | N | × | <u>×</u> | _ _ | × | | | | | _ | - | _ | က် ထ | | | | |
| | | 4 | | | What are the cortical and subcortical neural correlates of egocentric and exocentric orientation? | 6c2b | 4 ω | | ო | ო | ₩ | 8 | × | | × | × | × | | | 0 | | - | | ω, L | 9 | | | ···· |
| | | 4 | 4 | * | What are the structure-function relationships of the otolith organs and canals, including development, plasticity, and degeneration? | 6d1 | 4 | 5 | 0 | ဗ | _ | 8 | × | × | × | × | <u>×</u> | | | N | - | - | - | 10, | œ | | | |
| | 8 | | 4 | | What are the biophysical and physiological mechanisms of vestibular hair cell transduction and the physiology and pharmacology of transmission? | , eba | 4 | 4 | 0 | 7 | _ | 2 | × | × | × | × | × | | | Ν | <u>-</u> | - | - | 8, | 9 | | | |

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| Pa | | <u></u> | <u> </u> | 8 |
| | If single cells sense changes in gravity directly, what are the intracellular structural/functional mechanisms that are sensitive to gravity perturbation? Is the cytoskeleton organization of cells disturbed by gravity perturbation? How does the cell's cytoskeleton, outer membrane and nuclear envelope/nuclear matrix react to altered gravity, as a three-dimensional continuum of perception and structural integrity? | If single cells are too small to detect changes in the gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? | If multicellular systems are necessary for gravity sensing, how is this effected? What cellular structures and processes that extend across several cells might be involved? What aspects of cell-cell communication are affected? Would the requirements for cellular interaction/assembly increase sensitivity to indirect or environmentally mediated effects (e.g., reduction of cell-cell and cell-surface contact by dispersion of cells in microgravity)? | What are the mechanisms involved in the transduction of the stimulus of altered gravitational force to a cellular response? By what pathways is the perception of altered gravity relayed intracellularly and/or extracellularly? |
| Critical Question | If single cells sense changes in gravity of what are the intracellular structural/fundechanisms that are sensitive to gravity perturbation? Is the cytoskeleton organicells disturbed by gravity perturbation? the cell's cytoskeleton, outer membrane anuclear envelope/nuclear matrix react to gravity, as a three-dimensional continuun perception and structural integrity? | If single cells are to gravitational field di environmental chang response? Is the c currents at microgr | If multicellular syst sensing, how is this servictures and processeveral cells might I sell-cell communicat requirements for concrease sensitivity mediated effects (e. sell-surface contact nicrogravity)? | Mhat are the mechansduction of the gravitational force what pathways is elayed intracellul |
| | | If single cells are too small to detect ch gravitational field directly, what are th environmental changes responsible for response? Is the cessation of microco currents at microgravity responsible? | If multicellular syst sensing, how is this structures and processoveral cells might cell-cell communicat requirements for coincrease sensitivity mediated effects (e.cell-surface contact microgravity)? | What are the mech transduction of the gravitational force what pathways is relayed intracellul |
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All Critical Questions Which Would Require Ground Based Research

| 3 64 | * * * * * * * * * * | 1/3 | 2 | C1 C2 C3 C4 C5 Critical Question Qu | Quest# C | - | 2 | 6 | 4 | 2 | 9 | 7 8 | 6 | H | 5 | 1 1 2 | 5 | 14 | 15 | 16 | 1 | 8 | Group w/ | | other D | Disc |
|--|---|--|--|--|----------|---|---|-------------|---|---|---|-----|--------------|----------|--|-----------------------|---|----|--------------|-----------|--------------|--------------|-----------------|---------|---------|-----------|
| 3 4 * How does g developmer — Are the vestibular, | | How does g developmer — Are the vestibular, musculoske | How does government and development — Are the vestibular, musculoske | How does gravity affect organogenesis and the development of anatomical structures? — Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular, musculoskeletal) of young and adult animals | 71 | - | - | | - | 2 | е | × | × | × | × | × | | | _ | ν- | | - | 7, 8, | ري د | | |
| 5 * What are the op the circadian rhy to the mission so mission personn | 5 What are the circad to the mis mission press schedule. | * What are the circad to the mission pression pr | What are the circad to the mission principle schedule. | timal conditions for synchronizing that conditions for synchronizing thems of mission control persor shedules? How is performance is affected by their various were | رن 4 | | | | | | | × | × | | | | | | - | _ | - | - | | | | <u> </u> |
| 4 5 What are environm circadian | ۍ • | • What are environm circadian | What are environm circadian | 5 • What are the long-term effects of the space carlo environment on the interaction between the circadian system and ultradian and infradian rhythms, especially reproductive systems? | 4 | | | | | | | × | × | × | | <u>×</u> | | | 2 | - | - | - | | | | |
| 4 5 * What ar opioid s: events (reference environment) | Т | What ar opioid si events (reference environne | What ar opioid si events (| What are the hypothalamic-pituitary-adrenal and opioid system responses to normal space-flight events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, and environmental stimuli? | <u>5</u> | | | | | | | × | × | | | × | | | - | y- | | - | | | | ···· |
| 4 5 What a | | What a | What a flight or respon | 5 • What are the acute and chronic effects of space 2b3 flight on endocrine system homeostasis and responsiveness? | 6 4 | | | | | | | × | × | <u>×</u> | | × | | | | _ | - | - | | | | · · · · · |
| 4 5 * How do pharms permes action a | ÷ | 5 How do pharma permea action a | How do pharma permea | 5 * How does space flight affect the pharmacodynamics of hormone action, the permeability of the blood-brain barrier, and the action and metabolism of hormones? | 4 | | | | | | | × | × | ~ | ······································ | | - | | | | - | - | 4 , α | | | |
| 4 5 * How do long-ter | | 5 * How do long-ter and fur | How do long-ter and fur | 5 * How do altered biological rhythms associated with 2b5 long-term space flight affect hormone secretion and function and vice versa? | 4 | | | | | | | × | $\widehat{}$ | × | $\overline{}$ | $\stackrel{	imes}{-}$ | | | - | - | - | | | | | |

1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality

11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Table 3 Page

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All Critical Questions Which Would Require Ground Based Research

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All Critical Questions Which Would Require Ground Based Research

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All Critical Questions Which Would Require Ground Based Research

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Paralle//Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community Table 3

All Critical Questions Which Would Require

Ground Based Research

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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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All Critical Questions Which Would Require Ground Based Research

Table 3

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| | | | | | gravity affect selected phases in animals that | | _ | | - | | | | | | | | | | | | | | | | | | |
| | | | | | represent different species and phyla? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | How will gravitational fields, particularly | | | | | _ | | | | | | _ | _ | | | | | _ | | | | | |
| _ | | | | | microgravity, disturb the precise coordination and | ** | | | | | | | | | | | | | _ | | | | | | | | |
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| | | | | | Will aquatic animals perceive and respond to | | | | _ | | | | | | | | | | | | | | | | | | |
| | | | | | gravity as do their terrestrial counterparts? | | | _ | - | | | | | | | | | | _ | - | | | | | | | |
| | | | | | Those animals which pursue different life stages | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | in both environments may be particularly valuable | | _ | | | | | | | | | | | | | | | _ | | | | | |
| | | | | | for study. | | | | | | | | | | | | | , | - | | | | | | | | |
| | | | | 1, | occopy and observe porturbations of | 81116 | _ | | | | _ | × | | × | × | × | × | _ | _ | 2 | 2 | _ | က် | 4 | | | |
| | | | | n | | | | | | | | | | | | | | _ | _ | _ | _ | | _ | | | | |
| | | | | | circadian rhythms, both temporally and with | | | | | | | | | | | | | | | | | | | | | | |
| | | _ | | | respect to differentiation state? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | 5 | 5 * How do specific organs and tissues respond | 81119 4 | | | | | | × | | × | × | × | | | | N | N | | Ŋ | | | | |
| | _ | | | | developmentally to altered gravity, as | | | | | | _ | | | | | | | | | | | | | | | | |
| _ | | | | | demonstrated by the expression of selected target | | | | | | | | | | | | | _ | - | | | - | | | | | |
| | | | | | genes in transgenic mice with pre-determined | | | _ | | _ | | | | | | | | | | _ | | | _ | | | | |
| | | | | | genetic makeups? | | | _ | | _ | | | | | | | | | | | | | | , | ı | | |
| | | | | 'n | oung interactions be altered in | 811110 4 | _ | | | | | × | | × | × | × | × | | | _ | | _ | რ | 4, v, | `, | 00 | |
| | _ | | | | the space environment? | | | | | | | | | | | | | | | _ | | _ | | | | | |
| | | | | | - Will hatching or parturition occur normally? | | | | _ | | | | | | | | | | | _ | | | | | | | |
| | | | | | - What will be the effects on lactation, suckling | | | _ | | | | | | | _ | | | - | | | | | | | | | |
| | | | | | and related parent- young bonding mechanisms? | | | _ | - | | | | | | | | | _ | | | | - | | | | | |
| | | | | | - In the period of rapid post-natal growth, which | • | | | | | | | | | | | | | - | | | - | | | | | |
| | | | | | systems are the most sensitive to altered gravity | | | - | | | | | | | | | | | _ | | | | | | | | |
| | | | | | perturbations? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | 2 | 5 * What are the effects of gravity, in concert | 81111 | 4 | • | | | | × | | × | × | × | × | | | _ | <u>- 2</u> | _ | | | | | |
| | | | | | particularly with life in closed ecosystems, on | | | _ | | | | | | | | | | | | | | | | | | | |
| | | | | | sexual maturation? | | _ | \exists | \dashv | \dashv | \dashv | \dashv | 4 | _ | | | | | ┫ | 1 | 1 | \dashv | \dashv | | | 1 | |

All Critical Questions Which Would Require

Ground Based Research

| 5 | 22 | ਲ | 2 | C1 C2 C3 C4 C5 Critical Question | Quest# | 10 | Ë | 2 3 | - | ۳ | ٣ | 1 | ļα | [· | Ę | 1 | ٢ | 100 | \vdash | Ŀ | Ŀ | | _ | | | | | _ |
|---|----|----------|----------|--|---------|--------------|----|-----|---|---|------------|-------------|----|-----|----------------|--------------|----------|-----|----------|--------|----------|---|------------|----------|---|-------|------|---|
| H | | \vdash | ۲ | | | | :+ | 7 | す | T | ✝ | 4 | 4 | 2 | 2 | = | | 2 | + | _ n | | | בֿ מ | Group w/ | | other | Disc | |
| | | | n | Thow does gravity produce responses in cultured | 811112 | 4 | _ | | | | <u>-</u> - | × | × | × | × | × | | _ | - | ٥ | 6 | Ļ | - | س | 0 | | | , |
| | | | | cells that mimic those seen in chronologically aged | | | | | | | | | | | : | | | | - | 1 | 1 | | ŕ | | | D | | |
| _ | | | | cells, those isolated from accelerated aging | | | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | | syndromes, and senescent cells in vitro? | | | | | | | | | | | | | | | _ | _ | _ | | | | | | | |
| | | | | - Which de-limiters of lifespan have relevance to | | | | | | _ | _ | | _ | | | | _ | | _ | | | | | | | | | |
| | | | • | , | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | .c | * Is gravity a continuum in terms of | 0 V V V | | | | | _ | | ; | _ | ; | ; | | _ | | | - | | _ | | | | | | |
| | | | | stimulus/response? | 2 2 | , | | | _ | | | <u><</u> | | × | × | × | × | | _ | = | _ | _ | œί | 9 | | | | |
| | | _ | L | ************************************** | | | | | | | | | | | | | | | _ | | | | | | | | | |
| | | | <u> </u> | writed is the role of gravity in the evolution of | 8IVa2 | 4 | | | | | | × | × | × | × | × | × | | | _ | | | α | Ç | | | | |
| | _ | | | animal gravity sensors? | | | | _ | | _ | | | | | | | | - | _ | • | | - |) | 2 | | | | |
| | | _ | 'n | What are the basic properties and fundamental | SIVa3 | _ | | | | | _ | > | > | | | | | | | | | | | | | | | |
| | - | | | | 3 | | | | | _ | | < | < | < | < | ` | <u> </u> | | _ | _ | _ | _ | œ | | | | | |
| _ | | - | | ייים מופטוס מייים ביייים ממשליו איניים מיים מיים מייים מייים מייים מייים מייים מייים מייים מייים מייים מייים | | | _ | | | | | | | | | - | | | _ | | | _ | | | | | | |
| | | _ | | lo dii dilefed g-environment? | | | | | | _ | | | | | | | | | | | | | | | | | | |
| | | | 2 | *What is the specific role of calcium in information | 81Vb2 | 4 | | | | | | <u> </u> | | > | | | | _ | | | , | , | _ | , | | | | |
| | | | | | | | | | | | _ | < | | _ | - | | _ | | = | V | _ | | ю <u>,</u> | 9 | | | | _ |
| | | | | | | _ | | _ | | | | _ | | • | | _ | | | | | | | | | | | | |
| | | _ | | undergorie evolutionary expansion or diminution? | | - | | _ | - | | | | | | | | | | | | | | | | | | | |
| | | _ | S | * Are the second messengers and neurotransmitters | 8IVb3 | 4 | | | | | | > | | | | | | | - | | | | • | • | | | | _ |
| _ | | _ | | | | _ | | _ | | | | <u> </u> | | | - | | | | <u> </u> | _ | _ | _ | o. | 2 | | | | _ |
| _ | | _ | _ | acrose species or is thousand the second second | | - | _ | | | | | | | | _ | | | _ | | | | | | | | | | |
| | | | _ | for speed of for modulation infinite | | | | | | | | | | | | | _ | - | | | | | | | | | | |
| | | _ | _ | lior speed of for modulatory influences? | | | | | | | | | | | | | | | | | | | | | | | | _ |
| _ | | | Ŋ | Is there a relationship between the evolution of | NIV.1 | _ | - | | | _ | | > | | | | | | | | _ | | | | | | | | _ |
| | | _ | | į | | | | | _ | _ | | <u><</u> | | | | _ | | _ | 2 | _ | _ | _ | ω, | 9 | | | | |
| | | _ | _ | | | _ | | _ | | | _ | | | | | _ | | | | | | | | | | | | |
| | | | | a more complex gravity sensing end organ? Are | | _ | | | _ | | | | | | | | | | | | _ | | | | | | | |
| | | | | there common mechanisms that tie all gravity | | | | | | | | | | | | | | | _ | | | | | | | | | |
| | | | | sensors together over evolutionary history? | | _ | | | | | | | | _ | - | | _ | | | | | | | | | | | |
| | | | LC: | | 0.77.10 | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | 'n | OIVCZ | 4 | _ | | | | | × | × | × | ^ × | _ × | | | _ | _ | <u>-</u> | _ | ω | | | | | |
| | | | | curivey information about linear acceleratory | | | | | | | | | | | _ | _ | _ | | _ | _ | | | | | | | | |
| | | | | forces acting on the system? What is the basis of | | | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | | neural coding? | | | | _ | | | | | | | | | | | | | | | | | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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ole 3 Pag

All Critical Questions Which Would Require Ground Based Research

Table 3

| 5 | 67 | [2 | 5 | CA CS Critical Question | Quest# C | - | 2 | 3 | 4 5 | 9 | 1 | | 6 | 101 | 1 | 2 1 | 3 14 | 4 15 | 16 | 17 | 18 | Group w/ other | /w d | othe | r Disc | ပ္တ |
|---|----|-----|---------|---|----------|---|---|---|----------|----------|------------|---|---|-----|----------------|-------|-------------|----------|----------|-----|----|----------------|------|------|--------|-----|
| _ | 3 | 3 | 3 4 | " | 8IVc3 4 | _ | | | \vdash | \vdash | × | | | | _ | | | 2 | - | - | - | 60 | | | | |
| | | | | computer simulations of gravity sensor | | | | | | | | | | | | | | | | | | | | | | |
| | | | | information processing that can provide insignis and identify important questions for experimental | | | | | | | | | | | | | | | | | | | | | | |
| | | | | testing using scarce altered-g force resources? | | | | | | | | | | | | | | | | | | | | | | _ |
| | | | | What are the potential spinoffs in this work for | | | | | _ | | | | | | _ | | | | | | | | | | | |
| | | | | increasing understanding of other systems by use | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | | of similar metrious, or lor comparer recuiring 97: | 91Vc4 | | | | | | × | × | × | × | × | | | _= | _ | | - | 00 | | | | |
| | | | Ω | 5 Is there a fundamental pliniciple of gravity seried information processing that permits determination | | | | | | | | | | | | | | | | | | | | | | |
| | | | | of the 3-dimensional (3-D) linear acceleratory | | | | | | | | | | | | | | | | | | | | | | |
| | | | | environment of the body (in many invertebrates) | | | | | | | | | | | | | | | _ | | | | | | | |
| | | | | and of the head in vertebrates? | | | | | | | | | | | | - | - | | | | | _ (| | | | |
| | | | | Is there a relationship between otoconial or | 8IVc5 4 | _ | | | _ | | × | × | × | × | ≏ × | × | | _ | _ | _ | | xo | | | | |
| | | | | statolith load and the acceleratory environment, | | | | _ | | | | | | | | | | | | _ | | | | | | |
| | | | | and/or between this load and the neural substrate? | | | | | | | | | | | | - | | | | . 1 | , | | | | | |
| | | | ີເດ | * What are the principles of organization, and the | 8IVd1 4 | _ | | | | | × | × | × | × | <u>^</u> ×_ | × | | | Ξ_ | | | xo_ | | | | |
| | | | | inherent mechanisms, that underlie the adaptive | | | | | | | | | | | | | | | | | | | | | | |
| | | | | capability of gravity sensors when animals are | | | | | | _ | | - | | | | | - | | | | _ | | | | | |
| | | | | placed in altered-g environments? Are there | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | _ | | | | | | _ | | | | | | | | | | • |
| | | | | prevent adaptation? (Could a bottom-dwelling flat | | | | | | | | | | | | | | | • | | | | | | | |
| | | | | fish, like a turbot, adapt to decreased gravity?) | | | | _ | | | | | ; | | _; | | | | ٠. | | | a | | | | |
| | | | 'n | * Will animals bred in microgravity or hypergravity | 81Vd3 | 4 | | | | | <u>×</u> | | × | × | <u> </u> | | | | <u> </u> | | | 0 | | | | |
| | | | | be able to adjust readily to Earth's gravitational | | | | | | _ | | | | | | _ | _ | | | | | | | | | |
| | | | | environment, or will adaptation prove difficult | | | | | | _ | — | | | | | | | | | | | | | | | |
| | | | | because the animals are tuned to a gravitational | | | | | | | _ | | | | | _ | | | | | | | | | | |
| | | | | extreme? Is it Earth's environmental position, off | | | | | | | | | | | | | _ | | | | | | | | | |
| | | | | an extreme, that permits adaptive responses? | | - | | | | _ | | | | | | | | | | | | | | | | |
| | | | Ŋ | * Does chaos theory explain gravity sensor | 81Vd4 | 4 | | | | | <u>×</u> _ | | | | | | _ | N | _ | _ | | <u>。</u> | | | | |
| | | | | adaptation to an altered gravitational | | | | | | | | | | | | _ | | | | | | | | | | |
| | | | _ | environment? | | | | | | | | - | _ | | | ٦ | ㅓ | \dashv | \dashv | 4 | 4 | | | ı | | 1 |

| 010 | <u>ვ</u> | 3 | <u>4</u> | C2 C3 C4 C5 Critical Question | Ollo s t# | 0 | ۲ | ٢ | F | | ű | | ۲ | F | H | Į, | Ŀ | Ŀ | F | | <u> </u> | <u> </u> | | | | Г |
|----------|----------|-----|----------|---|-----------|----------|---|---|--|---|----------|--------------|-------------|-----------------------------|--|-------------|---|----------|--------------|--------------|----------|----------|----------|----------|--------|-----|
| - | _ | | 4 | 1986 | | _ | + | 7 | <u>- </u> | 2 | _ | 1 | 7 | - | _ | - | 2 | 14 | 2 | ٥ | 1711 | 8 | Group w/ | // other | r Disc | ပ္ပ |
| | | | n | o Will otoconial and/or statolith load change in a | 81745 | 4 | | _ | | | | ^ | × | $\frac{\times}{\mathbb{Z}}$ | <u>×</u> | <u>×</u> | | | - | 2 | - | α | | | | Т |
| | | | | sustained, affered gravitational environment, and | | | | _ | | | | | | _ | | | | | | | _ | | | | | _ |
| _ | | | | will the response be uniform across phyla and | | | | | | | | - | | | | | | | | | | | | | | |
| | | | | Species? | | | | | | | | | | | _ | | | | | | _ | | | | | |
| | | | 2 | * Does development of a gravity receptor in an | 8IVe1 | 4 | | | | | | × | _ <u>×</u> | <u>~</u> | <u> </u> | <u> </u> | | | _ | <u>`</u> | | | | | | |
| | _ | | | aftered-g environment affect the ability of the | | | | | | | <u></u> | | _ | | <u> </u> | <u> </u> | | | _ | | _ | <u>o</u> | 2 | | | |
| | _ | | | animal to mature and reproduce? | | | | | | | | | | | | | | | | | | | | | | |
| | | | 2 | 5 * Would gravity sensors of animals bred in a | RIVe2 | | | | | | | | | | > | _; | | | | | | | | | | |
| _ | | | | sustained, altered gravitational environment he | 1 | - | | | _ | | • | - | <u><</u> | <u><</u> | <u><</u> | <u><</u> | | | _ | <u> </u> | _ | <u>ω</u> | 9 | | | _ |
| | | | | different structurally and functionally from those | | | | | | | | | | | - | | | | | | | _ | | | | _ |
| | | | | of animals bred on Farth? Would the changes he | | | | | _ | | | | | | | | | | | | | | | | | |
| | | | | permanent? | | | | | | | _ | | | | | | | | | , | | | | | | |
| | | _ | u | 10 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | | | | | | | | | | | | | | | | | | | | | | |
| | | _ | n | o lis mere a critical time for exposure to 1-g for | 81Ve3 | 4 | | | | | ^ | _ × | × | × | × | | | _ | <u> </u> | - | _ | α | 9 | | | |
| | _ | _ | _ | development of a gravity sensor with features | | | | | | | | | _ | | <u>_</u> | | | | - | | - | <u>,</u> | 2 | | | |
| _ | | | | typically associated with those of animals confined | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | _ | to Earth's 1-9 environment? (Equal weight with 2 | | | | _ | | | | | | | | | | | | | | | | | | |
| | | | | above.) | | | | _ | | | | | | | _ | | | | _ | | | | | | | |
| | | 4, | 'n | If there is a critical period for exposure to 1-2 for | V | | | | | | | | | | | | | | | _ | | _ | | | | |
| _ | | | | lot get of state of the second value of the second of the | † D A C | - | | | | | <u> </u> | × | <u>×</u> | <u>×</u> | × | | | _ | - | <u>-</u> | _ | œ | 10 | | | |
| _ | | | | to control gravity seriou development, is it essential | | | _ | | | | | | | | | | | | | | | _ | | | | |
| _ | | | | decomplish this to provide for future plasticity | | | | | | | _ | | | | | | | _ | | | | | | | | |
| | | _ | _ | and for readaptability to Earth's 1-g? | | _ | | | | | | _ | | | | | | | _ | | | | | | | |
| | | 44) | 5 | 5 * Are there species differences in degree of | 81Ve5 | 4 | | | | | _> | ` | <u> </u> | _ | > | > | | | | 1 | | - | | | | |
| | | | | susceptibility to a developmental change in an | • | | | _ | | | ` | | | <u> </u> | <u><</u> | < | | | | _ | _ | xo` | 0 | | | |
| | | | | altered-g environment? | | | | | | | | _ | | | | | | | | | | | | | | |
| - | | u) | 'n | Would animals bred for many generations in second | 0.1/10 | | _ | | | - | | | | | | | | _ | | | | | | | | |
| | | | | retain their adaptive ability to an altered a force | 0 0 0 | 4 | | | | | <u>×</u> | | × | × | <u>×</u> | × | | <u> </u> | _ | _ | - | ω, | 10 | | | |
| | | | | Will this ability vary according to species? | | - | | | | | - | | | _ | | | | | _ | | _ | • | | | | |
| | | | ı, | selonds of Simples Control | | | _ | | | | _ | | | _ | | | | | | | | | | | | |
| | | n | ດ | 5 What are the mechanisms that permit central | 8IVf1 | 4 | | | | | × | _ | × | × | × | × | | | 7 | | _ | α | | | | _ |
| | | | | adaptation to novel inputs from gravity sensors in | | | | | | | | | | : | <u>: </u> | : | | | | - | _ | <u> </u> | | | | _ |
| | | | | an altered-g environment? Does rewiring take | | | | _ | | | | | _ | | | | | _ | _ | | | | | | | |
| \dashv | | | | place? | | _ | _ | | | | _ | | | | | | | | | | | | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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All Critical Questions Which Would Require Ground Based Research

| 5 | _ | ខ | 2 | SS | C2 C3 C4 C5 Critical Question | Quest# | Cr1 | 2 | က | 4 | 2 | 9 | 7 | 8 | 6 | 10 | 1-1 | 12 | 13 | 4 | 5 1 | 6 1 | 7 | 18 G | Group w/ | w/ other | er Disc |
|------------|---|---|------|----------|--|--------|-----|---|---|---|---|---|---|---|---|----|-----|----|----|----------|----------------|--------------|--------------|------|----------|----------|---------|
| | | | | 5 | _ | 81Vf2 | 4 | | | | | | × | X | X | X | × | × | | <u> </u> | | | <u>-</u> | ω | | | |
| | | | | | gravity sensor input and other sensory information in total 3-D orientation, over time, of the | | | | | | | | | | | | | | _ | | | - | | | | | |
| | | | | | organism? How does this change during evolution? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | 5 | n the | 8Va2 | 4 | | | | | | × | × | × | × | × | × | | | ~ | 2 | | 4 | | | |
| | | | | | circadian system and ultradian and infradian rhythms? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | ري * | 5 How does gravity affect interactions between the | 8Va3 | 4 | | | | | | × | | × | × | × | | | - | - 2 | 01 | - | 4 | | | |
| | | | | | circadian system and other homeostatic mechanisms? | | | | | | | | | | | | | | | _ | | | | | | | |
| | | | - 47 | 5 | 5 * What is the role of gravity on closed loop | 8Vb6 | 4 | | | | | | × | × | × | × | | × | | ., | - - | _ | | 4, | 00 | | |
| | | | | | regulatory systems (neuroendocrine, mechanisms, responsiveness, development)? | | | | | | | | | | | | | | | | · | | | | | | |
| | | | | ۍ * | ne and exocrine | 8Vb8 | 4 | | | | | | × | × | × | × | | × | | | ÷ | _ | _ | 4, | ထ် | 9 | |
| | | | | | processes? Neuro- axonal transport? Transitter | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | release and re-uptake processes? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | 3. | 5 * What is the role of gravity in the regulation and | 8Vb11 | 4 | | | | | | × | × | × | × | × | × | | | - | - | - | 4 | 2 | | |
| - <u>-</u> | | | | | onset of reproductive cycles (vaginal opening, | • | | | | | | | | | | | | | | | | | | | | | |
| | | | | | puberty, estrus cycles, tertilization, pregnancy, parturition, lactation, aging, life space, etc.)? | | | | | | | | | | | | | | | - | | | | | | | |
| | | | | ري ب | νοι | 8Vb12 | 4 | | | | | | × | × | × | × | | × | | | - | ~ | _ | က် | 4, | 10 | |
| | | | | | does gravity affect it and what are the mechanisms? | | | | | | | | | | | | | | | | | | | | | | |
| | | | _~~ | ري ب | responses to an artificial 1-g | 8Vb13 | 4 | | | | | | × | × | × | × | × | | | | _ | _ | _ | 4 | | | |
| | | | | | environment in space equivalent to 1-g responses on Earth? | | | | | | | | | | | | | | | | | | | | | | |
| | | | | , r | 5 * le 24 hour per day 1-a exposure necessary to | 8Vb14 | 4 | | | | | | × | × | × | × | × | | | | _ | _ | <u> </u> | 4 | | | |
| | | | | <u> </u> | what | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | is the minimum time? What are the optimal | | | | | | | | | | | | | | | | | | | | | | |
| | | | | _ | presentation characteristics of the G stimulus? | | | _ | | | | ┙ | _ | | | | _ | | | | | ٦ | _ | ┪ | l | | |

All Critical Questions Which Would Require Ground Based Research

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| | Quest# | 8VI3 | 8VI12 | 8VI16 | 11a1 | 11a2 | 11a3 | 11a4 | |
| | Question | 5 'Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? | 5 * Is the relationship between muscle and bone RVI12 necessary for an integrated response to attered gravity or do the systems respond independently? | | 5 • What is the degree of molecular complexity and its 11a1 evolution in circumstellar, interstellar, and protosolar environments? | 5 • What is the composition, structure, and inter-relationships between circumstellar, interstellar and interplanetary dust? | 5 What is the efficacy of chemical and physical 11a3 processes in the ptotosolar nebula for altering pre-existing materials and producing new compounds and phases containing the biogenic elements? | 5 * How has the formation and evolution of primitive 11a4 bodies modified the distribution, structure, and composition of pre-existing compounds and phases and provided mechanisms for production of new species? | 5 • What is the distribution, structure and composition 11a5 of presolar and nebula products in existing primitive materials in the solar system? |
| | Question | ological y? | * Is the relationship between muscle and bone necessary for an integrated response to attered gravity or do the systems respond independently? | eys, and nd which | its | ar, | 50 | ø. | on 11a5 |
| | 2 C3 C4 C5 Critical Question | ological y? | * Is the relationship between muscle and bone necessary for an integrated response to attered gravity or do the systems respond independently? | eys, and nd which | its | ar, | 50 | ø. | on 11a5 |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Page 58 Table 3

All Critical Questions Which Would Require Ground Based Research

Table 3

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| Г | Quest#Cr11 | 1157 4 | | | 11b11 4 | | | | 11c5 | | | | 1106 | | | |
| | Quest# Cr1 | ts of the sunlight spectrum 11b7 | reach the surface of the Earth, and what influenced | the timing? | | monoxide, rather than carbon dioxide, have been | supplied as the dominant carbon source at Earth's | surface? | | within the eubacteria, archaebacteria, and | eukaryotes by means of molecular phylogeny and | detailed comparative biology? | | integrate data on physiological evolution with | geological data indicating the course of | environmental development of the early Earth? |
| | 1 | ts of the sunlight spectrum 11b7 | reach the surface of the Earth, and what influenced | the timing? | 11611 | monoxide, rather than carbon dioxide, have been | supplied as the dominant carbon source at Earth's | surface? | lism 11c5 | within the eubacteria, archaebacteria, and | eukaryotes by means of molecular phylogeny and | detailed comparative biology? | 1106 | integrate data on physiological evolution with | geological data indicating the course of | environmental development of the early Earth? |

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TABLE 4

CRITICAL QUESTIONS THAT WOULD UTILIZE SPACELABS LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- 1 = Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- 3 = Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- science Specifically enabled by Moon and/or Mars Missions.
- 5 Basic Research Not Directly Applicable to Moon and/or Mars Missions.
- Indicates primary category of application.

CRITICALITY

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| 1. | Science Readiness Levels |
|----|---|
| | Only folklore of practitioners and anecdotal data available |
| | 2. Basic scientific concept formulated |
| | 3. Ground models developed, flight validation required |
| | 4. Flight validation performed |
| | 5. Countermeasures identified |
| | 6. Countermeasures tested |
| | 7. Operational requirements established |
| 2 | Technology Readiness Levels |
| | Technology need identified |
| | Technology and conceptual solution available |
| | 3. Component and/or breadboard validation in laboratory |
| | environment exist |

- 4. Flight validation performed
- 5. Systems/subsystem prototype demonstration in a relevant
- ground or space environment completed

 System prototype demonstrated in a space environment
- Actual system completed and flight qualified through test and Demonstration
- Actual system "flight proven" through successful mission operations
- 3. Schedule (information required by)
 1. = Near term < 5 years
 - 2. = Mid term 6-10 years 3. = Far term > 10 years
- 4. Effort Required
 - 1 Substantial
 - Moderate
 - 1 1 1 1 1 1 1 1
- Defined Sequence (Clearly defined sequential path for scientific investigation exists)
 - 1. = Yes 2 = No
- Parallet/Alternative Path (are parallel or alternative pathways appropriate)
 - 1. = Yes
- 2 = No 7. Ground-based
- x = Ground-based research required
- 8. Spacelab
 - Specelab would be used for research
 - EDO Spacelab needed for Extended Duration Orbiter
- 9. SSF
 - x = Space Station Freedom would be used

- 10. Centrifuge
- x SSF Centrifuge Facility would be used
- 11. Free Flyer

 x = Free flyer biosatellite
- 12. Lunar Base
- x = Lunar base would be used
- 13. Robotic Explorer
- x = Robotic explorer would be used
- 14. Other Requirements
 - Requirement for flight resources other then those identified in 8-10
- 15. Flight Validation Required
 - = Flight validation required
 - 2 = Not required
 - L Facilities Sufficient
 - 1. = Current ground facilities (NASA Centers, Universities
 - and provide industry) are sufficient.
 - Current ground facilities insufficient
- 17. Community Sufficient
 - There is a sufficient scientific community already committed or recruitable
 - Scientific community is insufficient
 - Attract New Community
 - 1. = Activity will attract new scientists
 - Activity will not attract new scientists
- 19. Group with other disciplines (can this activity be grouped with others from different life science disciplines?)
 - No, cannot be grouped
 - 2. Do not know at this time
 - Behavior, Performance and Human Factors
 - 4. = Regulatory Physiology
 5. = Cardiopulmonary
 - 6. = Environmental health
 - . = Musculoskeletai
 - Neumecience
 - k = Rediction Health
 - 10. = Cell and Developmental Biology
 - 11. = Plant Biology
 - 12 Life Support

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| ਹ | | ខ | 2 | ည | C2 C3 C4 C5 Critical Question | Quest# | Cr1 | 1 2 | 2 3 | 4 | 2 | 9 | 2 | 8 | 6 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | Group w/ | / ¥ | other | | Disc |
| * | 2 | 8 | | | What factors should be considered (e.g. | 1d2 | 1 | 2 | E E | - | 3 | 3 | × | × | × | | | × | | | - | Ì | _ | 2 | | | | | |
| | | | | | maintainability, reliability, operator discretion) when allocating functions between humans and | | | | | | | | | | | | | | | | | | | | | | | | |
| * | | က | | | What are the acceptable numbers and kinds of | 461 | - 4 / | <u>ئ</u> | 3 | 0 | | | × | × | × | | | × | | | - | | | - | 10 | | | | |
| | | | | | microorganisms in air, water, food, and surfaces? | | | | | | | | | | | | | | | | | | i | | | | | | |
| # | | • | | | What will the radiation environment be within the space vehicle and what factors influence the flux, | 7a8 | - | 24 | 4 | | က | ო | | × | × | | × | × i | × | | 2 | | - | - | | | | | |
| | | | | | energy, and linear energy transfer spectra of the radiation? | | | | | | | | | | | | | | | | | | | | | | | | |
| * | | | | | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events be improved? | 7a9 | - | - | 2 | ~ | | | × | × | × | 1000 | × | × | × | | N | - | - | _ | | | | | · |
| - | - | | | | What are the processing requirements necessary to handle human wastes? What are the health and safety requirements for the waste treatment | 9c168 | +- | N N | ъ — | N | N | | × | <u>H</u> | × | | | × | | | - | 8 | - | - | တ် (၁ | | | | <u> </u> |
| | | | | | subsystem? | | _ | | | - | | | | | | | | | | | | | | | | | | | |
| | | | _ | | Can the physico-chemical regenerative technologies and processes required for a Mars | 96425 | _ | 2 | - | | 7 | | × | × | × | | | × | | | - | 2 | _ | - | 10, | _, ઝ, | 9 | 12 | |
| | | | | | mission life support system function in the space environment? Consider: | | | | | <u></u> | | | | | | | | | | | | | | | | | | | |
| | | | | | - Maintenance of liquid-gas interfaces (e.g., for | | | | | | | | | | | | | | • | | | | | | | | | | |
| | | | | | | | | _ | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Iransfers and separations of liquids, solids, and cases | | | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | | | — Combustion | | _ | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | What is the composition of air, water, and | | _ | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | spacecraft systems and how is it monitored to | | | | - | | | | | | | | | | | | | | | | | | | | |
| | _ | | _ | | assure crew nearin saiety and performance: | | | | | | | _ | | | | | _ | | | | | | | | | | | | ٦ |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| Quest# | 101 | 101 | 4a1 | | 4a2 | 4a6 | 25 | 4p4 |
| Pa | | | 4 | | = | 4 | 4p2 | 4 |
| ical Question | What are the requirements for adequate quality of life as they relate to food, clothing, hygiene, vibroacoustics, lighting, and other personal needs (privacy, recreation) in spacecraft and habitats? | What are the behavioral correlates of physiological changes induced by the space environment? | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic | materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight conditions? | What are the effects of chronic exposure to ultrafine and larger (respirable and nonrespirable) particles on crew health, safety, and performance? | What is the effect of space flight on all microorganisms? | What technology is available to identify microorganisms in crew and environmental (air, water, surfaces) specimens. How are microorganisms controlled by anti-microbial procedures? |
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Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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|-----|----------|---|---------------------------------------|---|----------|----------|---|---|--------------|--------------|----------|---|------------|----------|-------------|----|----|---|---------------|-----|---------------|------------|-------|--------------|
| | 1 | | ļ | What are the effects of all potential atmospheric components, including contaminants and factors on physical and psychological well-being and crew partners. | 4c5 | 0 | 2 | က | ဧ | - | 1 × | × | × | | | × | | | - | _ | y- | ო | | |
| | | | | What are the thresholds required for gravity to have an effect? | 8la4 2 | 21 | 9 | | 2 | - | × E | × | <u>×</u> _ | <u>×</u> | | | | | - | 2 | - | | | _ |
| | | | | What are the differences, if any, between species and their tissues in their perception and responses to gravity? | 8la6 2 | - | N | | - | - | × E | × | × | <u>×</u> | | | | | - | 2 | <u>-</u> | | | t |
| | | | | Can plants successfully reproduce through more than one generation in space? | 8lb1 2 | <u>ო</u> | _ | | _ | - | × E | × | <u>×</u> _ | × | | | | | `` | 2 2 | - | 12 | | |
| | | | · · · · · · · · · · · · · · · · · · · | Is chromosomal integrity and behavior during cell division affected in microgravity? | 8lb2 2 | 4 | 9 | | | | × E | × | <u>×</u> | × | × | | | | - | 2 | <u>-</u> | 0 | | |
| | | | | Is cell, tissue, or organ differentiation affected in microgravity? | 8 lb3 2 | | | _ | 8 | | É | × | × | × | | | | | - | 8 | 2 | | | |
| | | | | What effect does microgravity have on embryogenesis and the ensuing stages of the life cycle of plants from maturity to flowering and senescence? | 81b4 | 2 | - | | N 1 | - | <u> </u> | × | × | × | | | | | - | ~ | 2 | | | |
| | | | ., | Are microgravity-grown tissues and organs competent? | 8165 | 2 | | _ | N | - | <u> </u> | × | × | × | × | | | | - | ~ | ~ | | | |
| | | | | Are the growth rates of higher plants or single cells affected by microgravity? | 81b6 | 2 | N | - | 8 | 8 | <u>E</u> | × | × | | | | | | | | | | | |
| | | 4 | | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | 8188 | 2 | α | | - | - | <u>g</u> | × | × × | × | × | × | × | | - | 8 | 2 | თ | | |
| | | | | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered in microgravity? | 8lc1 | 2 | ~ | - | - | _ | 2 | × | × × | × | | | | | - | 2 | 2 | 12 | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| ٥ | ८ | 肖 | 8 | ٢ | 8 | C2 C3 C4 C5 Critical Question | Quest# | 5 | 2 | 3 | 4 | 5 6 | 1 | - | 6 | ٤ | E | 121 | 3 | 14 | 151 | 161 | \vdash | 18 | Group w/ other | ther Disc |
| - | _ | | | | _ | What effect does microgravity have on the synthesis of storage and support polymers? | 81c2 2 | 2 2 | N | - | - | Z | × E | | 1 | × | ļ | | | | | | | | 2 | |
| - | | | | | | Are pathways for plant nutrient absorption altered in microgravity? | 81c4 | 2 | | _ | _ | | × | × | × | × | | | | | - 21 | - 2 | | - | 8 | |
| _ | | | | | | What are the effects of the space environment on long distance transport of water and on transpiration? | 81c5 2 | | | - | - | <u>z</u> | × £ | × | × | × | | | | | - 21 | <u>~</u> | <u>-</u> | | | |
| - | | ო | 4 | | _ 0 | How is the effect of gravity (and microgravity) on cells influenced by magnetic fields and radiation? | 81lc1 2 | - | - | - | - | ر د | × | × | × | × | × | × | × | | - 7 | - 2 | | <u>ი</u> _ | | |
| | | | 4 | | <u> </u> | Can crop plants produce sufficient edible biomass extra-terrestrially to support human crews? The | 9a1 2 | <u>ო</u> | ო | 8 | <u> </u> | - · | <u>×</u> | × | × | × | × | × | | | ~ | <u>-</u> | | <u>, 6</u> | , 10, 11 | |
| | | | · . | | <u> </u> | following constraints should be considered in studying this question: — Closed environments | | | | | | | | | | | | | | | | | | | | |
| | | | | | | Recycling — Limited space | | | | | | | | | | | | | | | | | | | | |
| | | | | | | - Gravity effects | | | | | | | | | | | | | • | | | | | | | |
| | | | | | 1 8 | Phytogenic volatile compounds and other trace contaminants | | | | | | | | | | , | | | | | | | | | | |
| | | | | | 1 | - Radiation Advantage Advantage - Advantag | | | | | | | | | | | | | | - | | | | | | |
| - | | | 4 | | <u> </u> | What conditions are required to optimize the food | 093 | , | | • | | | > | Ě | > | > | | ; | | | | _ | | | | |
| | | | | | Ō | d | | | | | | | < | 3 | <u> </u> | < | | < | | | <u> </u> | | | φ΄ | , 10, 11 | |
| | | | | | <u>a E</u> | plants: The following factors represent the minimum that should be considered in studying this | | | | | | | | *** | | | | | | | - | | | | | |
| | | | | | ð | question: | | | | | | | | | | | | | | _ | | | | | | |
| | | | | | | Light quantity, quality, periodicity, gas | | | | | | - | | | | | | | | | _ | | | | | |
| | | | | | <u>ರ</u> | - | | | | | | | | | | | | | _ | | | | | | | • |
| | | | | | 1_ | Root environment: substrate, nutrients, | - | | | | | | | | | | | | | | | | _ | | | |
| | _ | | | | <u>×</u> _ | volume, temperature, etc. | | | | _ | | | | | | | | | | | | | | | | |
| | _ | | | | <u></u> | Aerial environment: gas composition and | _ | | _ | | | | _ | | | | | | | | | | | | | |
| | | | | | ā. | pressure, temperature, planting density, etc. | | | | | - | | | | | | | | _ | | | | | | | - |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Table 4 Page 4

Page 5

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| ប | ন্ত | ਲ | ঠ | පි | C1 C2 C3 C4 C5 Critical Question | Quest# | Cr | 1 | <u>ო</u> | 4 | ς, | 9 | 7 | ω | 6 | 10 | 111 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | | dn | v/ of | Group w/ other Disc | isc | |
| +- | | | 4 | | What are the effects of adventitious biota (microbial and other) over long periods in a CELSS? | 9a4 | 2 | 2 1 | | 0 | က | - | × | <u>H</u> | × | <u> </u> | | × | | | - | 2 | - | 1 | 6, 1 | 10, | Ξ | | | |
| + | | - | 4 | | | 9a7 | ~ | 2 | - 8 | 21 | ო | | × | <u> </u> | × | | | × | | | - | 8 | - | - | 6, 1 | 10, | Ξ | | | |
| | ! | | | | Animals (aquatic and terrestrial, vertebrate and invertebrate) | | | | | | | · . | | | | | | | | | | | | | | | | | | |
| | | | | | — Algae Einesi | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | - rungi - Bacteria | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Tions at the collection of the | | | ··· | | | | | | | | | | | | ****** | | | | | | | | | | |
| | | | | | Synthetics | | | | | | | | | | | | | | | | | | | | | | | | • | |
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| | | _ | | | numans in space? I his question should consider at least the following: | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | - | - | | - Caloric requirements | | • | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | Will the nutritional requirements of the crew | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | change and require modified diets over time of flight | | | | | | | | | | | | | | | | | | , | | | | | | | |
| | | | | | — Fluid requirements | • | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | - Distribution of the macro nutrients (protein, | | | | | | | | _ | | | | | | | | | | | | | | | | | |
| | | | | | carbohydrate, lipid) | | | | | | | | | | | | | | | | | | | | | | | | | |
| | _ | | | | Fiber and micronutrient requirements | | _ | | | | _ | | | | | | | | | | _ | | | | | | | | | |

Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

| 25 | 었 | | * s t * | - | | | | 2 | 9 | | | 6 | 5 | = | 2 13 | 4 - | 15 | 16 | 7 | 8 | Jour | 1 ~ 1 | other | r Disc | ပ္ထု |
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| Wha | Son 4 | What are the acceptability criteria for foods and in 9t what priority order should they be evaluated? Some criteria include: — Safety and freedom from toxic substances and | 999 | <u>~</u> | | <u>-</u> | N | - | - | × | <u>^ </u> | × | | × | | | - | - | - | - | က် တ | 10 | | | |
| E E | <u> </u> | infectious agents How will the crew respond to diet on a Mars mission | | | | | | | | | · · · · · · · · · · · · · · · · · · · | | | | | | | | | | | | | | |
| 1 1 | | - Nutrient and attribute balance - Familiarity/cultural experience | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | <u> </u> | - Taste/texture/color/shape - Flexibility in preparation methods | | | | | | | | | | | | | | | | | | | | | | | |
| | <u> </u> | Cooking (time, complexity, etc.) Seasoning (diversity of options) Compatibility with other mean items | | | | | | | | | | | | | | | | | | | _ | | | | |
| | | Variety What food groups fulfill these requirements? How can the biomass candidates be used or | | · · · · · · · | | | | | | | | | | | | | | | | | | | | | |
| 4 E \(\angle \(\angle \) | <u> </u> | ~ | 9c21 2 | <u> </u> | ~ | Ν | ~ | N | - | × | × | × | | × | | | - | 0 | | - 69 | 9 | | | | |
| <u>.º > 3 a</u> | <u>.∞ > ≥ o</u> | issue of performance degradation? What are the best technologies for recycling the water required for a Mars mission to acceptable potable and hygiene levels? | 9c245 2 | 4 | <u> </u> | - | N | | - | × | × | × | | × | | | _ | ο. | - | - | တ က် | | | | <u>.</u> |
| 4 · > E | <u> </u> | ements for potable and Consider: on surfaces | 9c27 2 | 8 | φ | - | N | N | - | × | Ê | × | | × | | | - | 0 | - | - | 9 °E | | | | |

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| Question Quest# Cr1 | 9c29 2 3 | technologies can be adapted to a CELSS use, and what technologies will need to be developed for space application? | 8 | Consider: — Pests or pathogens (disease) SMACS | ts produced by humans, by procession by the plants themselves | — Atmosphere leakage | Perturbations in environmental controls Radiation | Microgravity Inamticipated ecological interactions | Scheduled or unscheduled system or mission events | - Failure of microbial cultures in algal | fermentation systems - Food variety | Ŋ | e effects of the space environment on 9e43 2 teractions with space systems and | 9f5a 2 | 9f6a 2 |
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Page 8

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | - 1 | e ti 3 Sy and xt se form | tion to | the - | What are the effects of the absence of gravity the generation, expression (period, phase, olitude and/or waveform) and entrainment of | | is it at the synchronizing agent (zeitgeber)? If not, is it necessary for the action of other | chronizing agents (light, exercise)? What is the role of gravity in the patonesy of | t | Is there a difference in the role of gravity | , <u>o</u> | What is the gravity threshold for it actions | latio | <u>ر</u> ج | otic: | d fo nts? |
| | CB | iring iring e, s res | t ar oosi ges | t is | Vha je g | diar | = 2 | Vhat | diar | £ ₹ | × | Vhai | ing \$ | ı, iisn | õ | ope plar |
| | 딁 | What are the optimal environmental conditions fensuring synchronization of circadian rhythms in space, and what are the most appropriate work-rest schedules for ensuring optimal health and performance? | What are the effects of pressure and gas composition in space flight and during EVA on changes on fluid and electrolyte regulation? | What is the role of gravity in the regulation of circadian rhythms? | What are the effects of the absence of graven the generation, expression (period, phase, amplitude and/or waveform) and entrainment. | circadian rhythms? | <u> = ==</u> | synchronizing agents (light, exercise)? — What is the role of gravity in the out | circadian rhythms? | <u>"</u> | complex organisms? | > | the regulation of circadian rhythms? Does this | gravity timestrong vary with title complexity of organism? | What robotic and automated procedures should | developed for planting, growing, and harvesting crop plants? |
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality Table 4

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| | | jo ja | | ģ | ಕ | > | result in permanent reflex deficits? What are the protocols for training effective ground teams and space crews in problem solving, enhanced communication, crew coordination, and | , <u>, , , , , , , , , , , , , , , , , , </u> | ė t |
| Critica | | How does prolonged space flight affect behavior and group dynamics (including species, sex, and | age differences)? What are the factors involved in integrating automated systems with human capabilities to productivity and reliability? What are | significant issues of control and intervention by human operators, and countermeasures for particular missions? | What are specific countermeasures that impact effectively upon bone and connective tissue structure and function? | Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with long-duration flights | result in permanent reflex deficits? What are the protocols for training effective ground teams and space crews in problem solving enhanced communication, crew coordination, and | What are the physical and cognisant performance capabilities and requirements of humans in different stages of space flight as a function of mission parameters, and remains an example the continuous continuous and continuous contin | physical environment? What are the effects of living in the space flight environment on cognitive functions (including attention, memory, information processing and decision-making) and on work capacity? |
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| | Į | چ چ | age differences)? What are the factors involved in integrating automated systems with human capabilities promote productivity and reliability? What | significant issues of control and intervention human operators, and countermeasures for particular missions? | What are specific countermeasures that impeffectively upon bone and connective tissue structure and function? | Will the decrease in afferent input to the vestibular, proprioceptive and somato-se systems associated with long-duration fil | result in permanent reflex deficits? What are the protocols for training effective ground teams and space crews in problem so enhanced communication, crew coordination, | What are the physical and cognisant perfor capabilities and requirements of humans in different stages of space flight as a function mission parameters. | physical environment? What are the effects of living in the space flig environment on cognitive functions (including attention, memory, information processing an decision-making) and on work capacity? |
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | Question | ne fundamental behavioral processes of | perception and sensation, learning and cognition, and motor skills change in space? What is the time course of adaptation? | What procedures are needed for analyzing missions 1f1 for their demands on human performance (e.g. task | analytical techniques and models): What are the special performance requirements and capabilities and equipment requirements for | extravehicular activity (EVA)? How do circadian rhythm cycles and sleep influence 1f11 performance and interact with the space | environment to affect ability to accomplish mission goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity? What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological chances incurred in space affect task | able to s on lon re most be applie | and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. What are the specific mechanisms underlying the orthostatic hypotension observed after flight? |
| | Question | ne fundamental behavioral processes of | | needed for analyzing missions numan performance (e.g. task | | ence roise | tes to | able to s on long- re most be applied, | the tries |
| | Question | ne fundamental behavioral processes of | | needed for analyzing missions numan performance (e.g. task | analytical techniques and models): What are the special performance requirements and capabilities and equipment requirements for | How do circadian rhythm cycles and sleep influence performance and interact with the space | environment to affect ability to accomplish mission goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity? What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological chances incurred in space affect task | performance? Of the various countermeasures available to combat adverse cardiovascular effects on longand short-duration missions, which are most effective, when and how should they be applied, | the tries |
| | | ne fundamental behavioral processes of | | needed for analyzing missions numan performance (e.g. task | | extravehicular activity (EVA)? How do circadian rhythm cycles and sleep influence performance and interact with the space | environment to affect ability to accomplish mission goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity? What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological change incurred in space affect task | able to s on long- re most be applied, | and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. What are the specific mechanisms underlying the orthostatic hypotension observed after flight? |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | utilized against these deteriorations? What is the time course and extent of muscle atrophy during either prolonged spaceflight o unloading? | utilized against these deteriorations? What is the time course and extent of muscle atrophy during either prolonged spaceflight ounloading? | ainst these deteriorations? time course and extent of muscle ring either prolonged spaceflight o | ainst these deteriorations? time course and extent of muscle ring either prolonged spaceflight o | | 5a1 | 2 | ო | | | | ღ | × | × | × | × | × | | | | | - | - | <u>.</u> | 7, 8 | | | |
| 2 • 3 4 How is muscle metabolism regulated during normal activity and exercise, after acute and chronic unloaded states, and during recovery from unloading? | 4 | | How is muscle metabolism regulated during nor activity and exercise, after acute and chronic unloaded states, and during recovery from unloading? | How is muscle metabolism regulated during nor activity and exercise, after acute and chronic unloaded states, and during recovery from unloading? | | 5a2 | 8 | ო | е | | - | ო | × | × | × | × | × | | | | 4 | | | 4 | 'n, | _ | | |
| • What are the effects of altered levels of hormon and their receptors in regulating the physiology unloaded muscle? | What are the effects of attered levels of horm and their receptors in regulating the physiologual unloaded muscle? | What are the effects of attered levels of horm and their receptors in regulating the physiologual unloaded muscle? | What are the effects of attered levels of hormon and their receptors in regulating the physiology unloaded muscle? | What are the effects of attered levels of hormon and their receptors in regulating the physiology unloaded muscle? | es of | 5b3 | N | С | 2 | | | က | × | × | × | × | × | | | - | - | - | - | 4, | , 5, | 7, 8 | | |
| What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and | | | What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and | What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and | | 5b4 | N | e e | 2 | _ | | က | × | × | × | | <u>×</u> | | | 8 | - | - | - | 3, 7, | αo | | | |
| function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuschar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuscluar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuschar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuscluar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuscluar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | | | | | | , | | | | | | | | | | | | | | | | | | |
| What are the effects of unloading on the muscular intracellular and extracellular matrix? | What are the effects of unloading on the musca intracellular and extracellular matrix? | What are the effects of unloading on the musca intracellular and extracellular matrix? | musca | musca | | 5b6 2 | <u></u> | <u></u> | - 7 | | | ო | × | × | <u>×</u> | | _× | | | | - | | | 7 | | | | |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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2

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 2 | ္မ | 3 | ည် | C2 C3 C4 C5 Critical Question | Quest# | C 1 | 2 | 3 | 4 | 5 6 | | ∞ | ၈ | 의 | Ξ | 12 | -3 | 4 | 2 | ٥ | = | 9 | 2 | \$ | Group W oursi | | ١. |
| ٦ | 6 | 4 | $oldsymbol{\perp}$ | the rate, extent, and time course of bone | 5c1 | 2 3 | 3 | + | - | <u></u> | <u>×</u> | × | × | × | | × | | | <u> </u> | _ | - - | <u>ო</u> | Ŋ | ۲, | | | |
| | | | | and connective tissue loss for different areas of | | | | | | | | _ | | | | | | | | _ | _ | _ | | | | | |
| | | | | the body during exposure to microgravity or | | - | | | | | | _ | | | | | | | | | | | | | | | |
| | | | | simulated microgravity? How is the time course | | | | | | | | | | | | | | | | | | - | | | | | _ |
| | | | | of regional tissue loss correlated with changes in | | | | | | | - | | | | _ | _ | | | _ | | | | | | | | |
| | | | | Ε | | | | | | | | | | | _ | | | | | _ | | _ | | | | | |
| | | | _ | site? To changes in regional microcirculation? To | | _ | | | | | | | _ | | | | | | | | _ | | | | | | |
| | | | _ | other regional and systemic factors? | | - | | | | | | | | _ | | | | | , | , | <u> </u> | <u>_</u> ; | 4 | ١ | | | |
| , | m | 4 | | Which endocrine and nutritional processes are | 5c2 | 2 | က | _ | _ | () | <u>~</u> ല | × × | <u>×</u> | <u>×</u> | _ | <u>×</u> | | | | _ | | <u>'</u> - | ~ 1 | | | | |
| <u> </u> |) | | | required for maintenance of bone and connective | | | | | | | | _ | _ | | | | | | | | | | | | | | |
| | | | | tissue? How do these processes interact with | | | _ | | _ | | _ | | _ | | | | | | | | | | | | | | |
| | | | _ | mechanical loading? Are these processes affected | | | | | | | | | - | | | | | | | | | | | | | | |
| | | | _ | by space-flight? | | | | | | | | | | | | | | | | | | | | | | | |
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| * * | <u>ო</u> | 4 | _ | Is bone loss reversible in terms of mass, unra- | 200 | | | | _ | <u>-</u> | - | | | _ | | | | | | | | | | | | | |
| _ | | | | and micro-structural organization, and | | _ | | | | _ | _ | | | | | | | | | | | | | | | | _ |
| | | | | microstructure? To what extent do irreversible | | | | | | | | | _ | | | | | | | | | _ | | | | | |
| | | | | architectural adaptations affect structural | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | integrity? | | | | | | | | _ | - | _ | | -> | | | | ¥ | • | Ţ | _ | | | | |
| ٥ | - | 4 | | How does mechanical stress and changes in stress | 2c8 | 7 | 2 2 | _ | _ | | ` _ | <u>^</u> | <u>×</u> × | <u><</u> | <u><</u> | <u> </u> | | | | | - | - | | | | | |
| | | | | contribute to bone and connective tissue | | | - | | | | _ | _ | | | | _ | | | | | | | | | | | |
| | | | | formation? Are stress and/or changes in stress | | | | _ | | | | | | | | | | | | | | | | | | | |
| | | | _ | required for continued structural integrity? | | | | | | | | | | | | | | | , | | , | | 7 | | | | |
| 2 | رن | 4 | | What are the critical characteristics or | 5c9 | 8 | 2 | _ | _ | - | က | <u>^</u> | ^ × | × × | <u>×</u> | | | | | | | _ | | | | | |
| 1 | | | | components of normal daily tissue stress and | | | _ | | | | | | - | | | | | | | | | | | | | | |
| | = | | | strain histories that regulate bone and connective | | | | | | | | | _ | | _ | | _ | | | | | | | | | | |
| | | _ | _ | tissue development, maintenance, and adaptation? | | | | | | | | | | | | | | | | | | | | | | | _ |
| | | _ | | How are these characteristics affected by | | | _ | | | | | | | | | | _ | | | _ | | | | | | | |
| | _ | | | microgravity? | | _ | | | _ | | | | | | | | | | | | | | 7 | _ | | | |
| _2 | • | 4 | | How are regional changes in bone and connective | 5c10 | 2 | 2 | _ | | _ | က | × | × | <u>×</u> ×_ | <u>×</u> _ | | | | | | | | | | | | |
| _ | | | | tissue related to regional changes in muscle | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | tissue? | | | ㅓ | 4 | 4 | | | 1 | 1 | 1 | \dashv | \dashv | ┨ | 4 | 4 | _ | |] | | | | | |

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | Question Quest# C | 4 How are neuromuscular activation patterns and 5c11 2 musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to 1-g? | 4 What are the patterns of in-vivo mechanical 5d1 2 loading (e.g., tissue strain, stress, strain rate, stress rate)in normal and low-g environments? | What are the bone and connective tissue markers 5d3 2 of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used to investigate and predict regional changes in bone metabolism? | What key elements of bone and connective tissue 5d6 2 structural assembly impact the biomechanical properties? | Are there specific load histories that affect the 5d7 2 macromolecular assembly of connective tissues? | What are sensory inputs and coordination of 6b2 2 muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | What are the optimal countermeasures for motor 6b3 2 readaptation to partial-g or 1-g after adaptation to microgravity? | What adaptive processes modify motor control 655 2 systems? What is the dynamic range of adaptation of motor responses in altered states of gravity? | What processes explain the altered perceptions of 6c5 2 joint and body position in microgravity? |
| | 2 C3 C4 C5 Critical Question Quest# C | How are neuromuscular activation patterns and 5c11 2 musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to 1-g? | What are the patterns of in-vivo mechanical 5d1 2 loading (e.g., tissue strain, stress, strain rate, stress rate)in normal and low-g environments? | What are the bone and connective tissue markers 5d3 of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used to investigate and predict regional changes in bone metabolism? | 546 | Are there specific load histories that affect the 5d7 2 macromolecular assembly of connective tissues? | What are sensory inputs and coordination of 6b2 2 muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | 6b3 2 | • What adaptive processes modify motor control 6b5 2 systems? What is the dynamic range of adaptation of motor responses in attered states of gravity? | What processes explain the altered perceptions of 6c5 2 joint and body position in microgravity? |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Chitcality
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Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 2 . | | 4 | 1 | What are the joint effects of radiation and | 811113 | 2 1 | | - | 1 | 2 | e | × | × | <u>×</u> _ | × | × | | | | _ | <u>-</u> _ | <u></u> | | | | |
| | | | | microgravity? | | | | | | | | | | | | | | | | _ | | | | | | |
| | | | | - How do neoplasms common to chronoughcal | | | | | | | | | | | | | | | | | | | | | | |
| | _ | | | aging relate to illinitation of cell mespair and | | | | | | | | | | | _ | | _ | | _ | | | | | | | |
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| 2 * | ო | | | What is the role of gravity in the regulation of the | 8Vb2 | 2 | 2 | N | N | N | 2 | ` - | <u>`</u> | <u><</u> | <u> </u> | <u> </u> | | _ | | | | _ | | | | |
| | | | | distribution, composition, and pressure of | | | | | | | _ | | | | _ | | - | | | | _ | _ | | | | |
| | | _ | _ | water/fluids in living systems from cells to | | | | _ | | _ | | , | | | | | | | _ | | _ | | | | | |
| | _ | | | complex organisms? How do these changes | | | _ | | | | | | _ | | | | | | - | | | _ | | | | |
| | | | | influence other homeostatic and regulatory | | | | _ | _ | | | | | . — | | | | | | | | | | | | |
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| _ | | | | mechanisms? | | | _ | _ | | - | | | | _ | > | > | | · | <u> </u> | | _ | C. | 7 | | | |
| ċ | ۲ | | _ | is musculoskeletal growth, development, and | 8V11 | 2 | <u>-</u> | _ | _ | က | - | × | <u>~</u> × | <u>< </u> | <u><</u> | <_ | | | _ | | | <u>`</u> | : | | | |
| 4 | 2 | | | Linetian pomorphised during enaceflight and can | | | - | | | | | | | | | | | _ | | | | _ | | | | |
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| | | | | and functional systems that should be examined | | _ | | | - | | | | _ | | | | | _ | | | | _ | | | | |
| | | - | | carefully are: (1) the postural muscles, (2) muscle | | | | _ | | | | | | | _ | | | | | | _ | _ | | | | |
| | _ | | | spindles, (3) weight/load-bearing bones and joints, | | | _ | | | | | | | | | | | | | - | | | | | | |
| | | | _ | (4) intervertebral discs. (5) the architecture of | | | | | | | | | | | | | | | | _ | | | | | | |
| | | | | the connective tissues of the body and (6) | | | | | | | | | _ | | _ | | | | | | _ | | | | | |
| | | | | musculoskeletal innervation. | | | | | | | | | _ | _ | | - | | | | | | | c | | | |
| ٥ | • | | | What is the role of fluid redistribution in the | 8V14 | 7 | 2 | 2 | 8 | 8 | ო | × | × | × × | <u>×</u> | × | | | | _ | | į, | 0 | | | |
| <u> </u> | | | | response of the musculoskeletal system to altered | | | | | | | | | | | | | | | | | _ | - | | | | |
| | | _ | | gravity and how does gravity impact the | | | _ | - | | | | | _ | | | | | | | _ | | | | | | |
| | | | _ | homeostasis of fluid compartments within tissues? | | | _ | | | | | | | | | | | | | | | | | | | |
| _ | _, | | | where circulation and adaptation to | 8/19 | 2 | <u> </u> | _ | _ | 7 | က | × | × | × | _ | × | | | - | _ | <u>-</u> | <u>`</u> | | xo | | |
| Ŋ | _ | | _ | With Signification and incomposition and incomposition with the state of the state | · • | | | _ | _ | _ | | | | | _ | _ | | | | _ | | _ | | | | |
| | | | | spaceflight? Are the signals the same as those | _ | | _ | | _ | | | | | | | | _ | | _ | | | | | | | |
| _ | | | | found in biomechanical unloading on Earth? | | | | _ | | | | - | | | | _> | | | · | <u> </u> | _ | _ | α | | | |
| 8 | * | | | What local changes occur in the musculoskeletal | 8V110 | 8 | - - | <u>-</u> | <u>-</u> | 7 | ო | × | × | <u> </u> | <u><</u> | <u><</u> | | | _ | | <u> </u> | |) | | | |
| | | | | system in response to changes in stresses, | | _ | | | | | | | | | | | | | | _ | | | | | | |
| | | | | strains, and strain rates? | | | | | - | _ | _ | | | ┪ | 4 | 4 | _ |] | 1 | 1 | 1 | ┨ | ١ | | | |
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 1 | = | Do various risk factors(e.g., age, gender, speci strain (race), nutrition) modulate the musculoskeletal response to altered gravity? | What are the major human factors principles that govern optimal assignment of responsibilities between space crews and ground teams and among | Gew and team members? What ground-based organizations are required for effective support flight crew performance on a Mars mission? | What are the critical elements and processes involved in decision- making by ground teams and space crews operating autonomously or in combination? | What are the optimal communication procedures for coordination among crew members and between ground and space crews? | What are the human factors issues in teleoperation? | What are the anthropometric requirements for work stations to accommodate individual team members to maximize performance? | What are the mission specific design and protocol requirements for telecommunications to optimize crew performance? | What are the most effective schedules for work, rest and recreation, exercise and sleep for enhancing human performance and adaptation during long-duration exposure to snace? | How is workload optimized for various space explorations? |
| ŀ | C1 C2 C3 C4 C5 Critical | □ w E | <u>> ŏŏ</u> | 5 5 € | <u> ≥ ≅ 8</u> | <u>≯ ō g</u> | <u>≯ •</u> | ₹ ₹ | <u> </u> | <u>≱ 5 m b</u> | 운 ※ |
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Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| [2 | 5 | [5 | 12 | TO T | CF | Calcalcalcalcritical Question | Quest# | C - | 2 | ၉ | 4 | 5 6 | 4 | 8 | 6 | 10 | 11 | 121 | 13 | 4 | 5 16 | 6 17 | 18 | | Group w/ | v ot | other | Disc |
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| | J | | | | | capabilities are best suited for obtaining | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | performance data in flight? | | | | | | - | | | | ; | | ; | | | | | | | | | | |
| _ | * 2 | | 4 | | | What are the effects of the space environment on | 2a1 | <u>ဧ</u> | | _ | N | 2 | × | <u>×</u> | <u>×</u> _ | × | | ×_ | _ | <u>-</u> | | | | ν, | 4, v, | ó | | - |
| | | | | | | sleep, sleep cycles, or the generation, expression | | - | | | | | | _ | | | | | | | | _ | | _ | | | | |
| _ | | | | | | (period, phase, amplitude and/or waveform), and | | - | | | | | | | | | | | | | | | | | | | | |
| | | | | | | entrainment of metabolic, endocrine, reproductive, | | | | | | | _ | | | | | _ | | | | | _ | | | | | |
| | | | | _ | | and/or behavioral circadian rhythms? Of these | | _ | | | | | | | | • | | | | - | | | | | | | | |
| | | | | | | effects, which result from altered gravity and | | | | | | 1 | | | _ | | | _ | _ | | | | | | | | | |
| | | | | | | which result from other environmental factors? | | | | | | | | | _ | | | | | _ | | | • | | | • | | |
| | ċ | * | | | | What are the effects of exercise on circadian | 2a6 | 3 | 2 | N | 7 | 2 | × | <u>×</u> | × | × | | × | | _ | - | _ | | <u>က်</u> | 4. V. | à | _ | |
| | 1, | | _ | _ | | whythe and close? What pharmacological and | | | _ | | | | _ | | | | _ | | | | | | | | | | | |
| | | | _ | | | stock (colored state -) : | | | | | | | _ | _ | _ | | _ | | _ | _ | | | | | | | | |
| | | | _ | | | nonpharmacological (e.g. lignt, exercise) agents | | | | | | _ | | | _ | | | | | | | _ | | _ | | | | |
| | | | | | | can be used to reset the human biological clock? | | | | | | | | | | | | | | | | _ | | | | | | |
| | | | | | | What are the effects of routine administration of | | | | | | | | | | | | | | | | _ | _ | | | | | |
| | | | | | | pharmacological agents in space on circadian | | | | | | | | | | | | | • | | | | | | | | | |
| | | | | _ | _ | rhythms and sleep? | | | | | | | | | - | | | ; | | | _ | | | • | r | | | |
| | , N | <u>ო</u> | 4 | | | What roles do age and gender play? Is there a | 2a11 | | 2 | ო | 7 | - | × ε | <u>×</u> | <u>×</u> | | | × | | | | | | 4. | 'n | | | |
| | | | | | | response of the circadian system to the space | | | | | | | | | | | | | | | | | | | | | | |
| | | | | _ | _ | environment? | | | - | | | | | | | | | | | | | | | | 1 | | | |
| | ٠ | <u>ო</u> | | | | Does the well documented decrease in red blood | 2c1 | <u>.</u> ღ | 4 | 7 | က | N N | <u>റ</u> ന | × × | <u>×</u> | <u>×</u> | × | | | | | | | 4, | | | | |
| _ | | | | | | cell mass termed "anemia of space flight" | | | | | | | . | | _ | | | | | | | | | | | | | |
| | | _ | | _ | _ | represent a normal microgravity-associated | | | | | | | | | _ | | | | | | | | _ | | | | | |
| | | | | | | adaptive process (self-limiting) or a transient | | | | | | | | | | | | | _ | | | | | | | | | |
| | _ | | | _ | | response (self- correcting) to changes brought | | | | | | | | | | | | | | | _ | | _ | | | | | |
| | _ | | | _ | | about by various space-flight-related stimuli | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | (stressors)? | | | - | \dashv | 4 | コ | ヿ | \dashv | \dashv | \dashv | 4 | _ | | 4 | ┪ | \dashv | \dashv | \dashv | | ١ | l | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| <u> </u> | Question Quest# | cell 2c3 | 3y 2e1 | alytical 2e2b ce flight | erlying the negative 2e3 I lean body mass What are the ig dietary | 265 US re | digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? |
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| | Question Quest# | cell 2c3 | cellular is? efficiency 2e1 there in | 2e2b | negative 2e3 y mass the | 265 US re | digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? |
| <u> </u> | Question Quest# | What is the most effective way to restore red cell 2c3 mass during simulated and actual microgravity? Should red cell mass be restored during space flight? Are these acute or chronic changes and are they of sufficient magnitude or duration to pose an unacceptable medical risk and warrant the development of countermeasures (prophylactic or therepoutic)? Formulate mathematical and | transient response to altered load histories? Is the basal metabolic rate and metabolic efficiency 2e1 altered during extended space flight? Are there changes in energy metabolism and storage in | What are the optimal noninvasive microanalytical 2e2b methods and techniques for use during space flight to monitor nutritional status? | What are the mechanisms underlying the negative 2e3 nitrogen balance and changes in lean body mass incurred during space flight? What are the possible interventions, including dietary afterations in proteins and aming added? | Do the effects of space flight require added 2e5 supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient | digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? |
| <u> </u> | Quest# | What is the most effective way to restore red cell 2c3 mass during simulated and actual microgravity? Should red cell mass be restored during space flight? Are these acute or chronic changes and are they of sufficient magnitude or duration to pose an unacceptable medical risk and warrant the development of countermeasures (prophylactic or therapeutic)? Formulate mathematical and | transient response to altered load histories? Is the basal metabolic rate and metabolic efficiency 2e1 altered during extended space flight? Are there changes in energy metabolism and storage in | 2e2b | negative 2e3 y mass the | Do the effects of space flight require added 2e5 supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient | digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? |

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Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 212 213 214 215 215 216 217 218 218 218 219 219 219 219 219 219 219 219 219 219 | 4 | | | What is the time course and nature of body composition change due to space flight? Do | | | ري ک | 2 | 2 | | × | × | × | × | | | | _ | - | | - | | | | | |
| 212 3 5 6 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | - | | · · | changes in body composition (age and gender) have an effect on crew health and performance? | | - | - | | | | | | | | | | | | | | | | | | | |
| 2f3 3 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | ۵ 4 | | · | What are the fluid and electrolyte regulating mechanisms underlying the cardiovascular responses to microgravity? | <u></u> | | 9 | 7 | | | | × | × | × | | × | | - | - | - | - | | | | | |
| 2f5 3 2 1 3 1 2 2 2 1 3 1 2 2 2 2 1 3 1 2 2 2 2 | 6 4 | | | What are the mechanisms for the chronic adaptive shifts in fluid and electrolytes during space flight? | | | α | 8 | | | | × | × | × | | × | | - | - | _ | - | _ | | | | |
| 215 3 2 1 3 1 2 2 2 2 3 2 1 3 1 2 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 2 2 3 3 3 3 2 2 2 2 3 2 2 3 | | | | How does the new steady state affect the body's ability to respond to heat stress, electrolyte loading, EVA, and countermeasures? | | | | | | | | | | | | | | | | | | | | | | |
| 218 3 2 2 3 2 2 3 2 2 3 2 2 3 3 3 2 2 2 3 | | | | | | | | ო | | | | × | × | | | <u> </u> | | <u>-</u> | | | - | _ | | | | |
| 2110 3 3 2 2 2 2 1 3 3 4 4 3 3 3 3 3 3 4 4 4 4 4 4 4 4 4 | ъ 4 | | | What are the effects of circadian rhythm changes in space flight on the responsiveness of the fluid and electrolyte system? | | | N | ო | | | | | × | × | | × | | | | _ | _ | _ | | | | |
| 3a4 3 3 3 3 1 2 X X X X X X X X X X X X X X X X X X | ۵ 4 | | | What are the roles of renal blood supply and renal electrolyte handling in extracellular fluid volume control during simulated and actual microgravity? | | | N | 8 | | | | | × | × | | × | | - | | | - | 4 | | | | · |
| 3a5 3 6 3 2 1 3 X X X X X X X X X X X X X X X X X X | e | | | What is the relationship between the cardiovascular adjustments to space flight and those occurring in Earth-based models such as bedrest, immersion, and head-down tilt? | | · · · · · · · · · · · · · · · · · · · | ო | ო | | | | | × | × | | × | | | | - | - | <u> </u> | | | | |
| | | | | Are the baroreflexes modified by space flight and how do these affect orthostatic tolerance? Are chemoreflexes and osmoreflexes modified by space flight and how do these affect orthostatic tolerance? | 3a5 | | | ო | | | | | × | | × | × | | - | _ | _ | - | | | | | |

Critical Questions That Would Utilize Spacelabs

Table 4

| C3 C4 C5 Critical | C4 C5 Crit | cs Crit | 5 Criti | Sign | ical Question | Quest# | 2 | 1 2 | | 8 | | 5 6 7 | <u> </u> | <u> </u> | 6 | 10 | = | 12 | 13 | 14 | 15 | 16 | [1] | 18 | | A OF | Group w/ other | i | |
|---|---|---|---|---|--|--------|---------------|---------------|---------------|-------------------|--------------|--------------|----------|----------|---|----|---|----|----|-------------|----|------------------|--------------|----|----------|------|----------------|---|-----|
| How are countermeasures to adverse cardiovascular effects of long- duration space flight affected by changes in fluid distribution? | How are countermeasure cardiovascular effects of flight affected by change | How are countermeasure cardiovascular effects of flight affected by change | How are countermeasure cardiovascular effects of flight affected by change | How are countermeasure cardiovascular effects of flight affected by change | s to adverse long- duration space s in fluid distribution? | 3a10 | 6 | 2 | 9 | 6 | | က | × | × | × | × | | × | · | <u> </u> | | · - | | | | 2 | 3 | | , I |
| 4 Are there appropriate animal and/or compute models for studying each functional element or cardiovascular adjustments to microgravity? | | Are there appropriate an models for studying each cardiovascular adjustmen | Are there appropriate an models for studying each cardiovascular adjustmen | Are there appropriate an models for studying each cardiovascular adjustmen | imal and/or computer functional element of nts to microgravity? | 3a11 | m | - | - | ю — | <u>ო</u> | - | × | × | × | × | | × | | | | - | - | - | r. | | | | |
| Are there changes in cardiac performance and contractile efficiency during long term exposumicrogravity? | | Are there changes in card contractile efficiency durin microgravity? | Are there changes in card contractile efficiency durin microgravity? | Are there changes in card contractile efficiency during microgravity? | liac performance and ng long term exposure to | 3a26 | ю. | 4 | <u>က</u> ထ | <u>ო</u> | | | × | × | × | × | × | | | | _ | - | - | | ıcı | | | | |
| ls pulmonary function altered in long-duration space flight at rest, exercise, or in a disease state? | ls pulmonary function afte space flight at rest, exercistate? | Is pulmonary function after space flight at rest, exercitate? | Is pulmonary function after space flight at rest, exercitate? | ls pulmonary function alte space flight at rest, exerci state? | red in long-duration se, or in a disease | - 3b6 | е 7 | 4 | <u>m</u> | <u>ო</u> | | | × | × | × | × | | '× | | | - | - | _ | - | ıo. | | | | |
| What are the physiological similarities and differences of ground- based models of muscle atrophy and fiber transformation and weightlessness-induced muscle atrophy and fiber | | What are the physiological differences of ground- base atrophy and fiber transform weightlessness-induced mus | What are the physiological differences of ground- base atrophy and fiber transform weightlessness-induced mus | What are the physiological differences of ground- base atrophy and fiber transform weightlessness-induced mus | similarities and d models of muscle ation and scle atrophy and fiber | 5a4 | <u>ო</u> | <u>ო</u> ო | | | | ო | × | × | × | × | | × | | | 0 | - | - | _ | က် | 7, 8 | | | - |
| transformation? How valid are ground-based models for studying the characteristics of space-flight-induced muscle changes? What are the molecular signals and mechanisms that are responsible for the control of muscle hypertrophy and atrophy, and what are the specific stimuli that are generated by exercise or disuse to signal increased or decreased protein | transformation? How valid models for studying the ch space-flight-induced muscle What are the molecular sign that are responsible for the hypertrophy and atrophy, are specific stimuli that are ger disuse to signal increased o | transformation? How valid models for studying the ch space-flight-induced muscle What are the molecular sign that are responsible for the hypertrophy and atrophy, are specific stimuli that are ger disuse to signal increased o | transformation? How valid models for studying the ch space-flight-induced muscle What are the molecular sign that are responsible for the hypertrophy and atrophy, are specific stimuli that are ger disuse to signal increased o | transformation? How valid models for studying the ch space-flight-induced muscle What are the molecular sign that are responsible for the hypertrophy and atrophy, are ger specific stimuli that are ger disuse to signal increased o | are ground-based aracteristics of changes? als and mechanisms control of muscle nd what are the nerated by exercise or referessed protein | 5b1 | <u>ო</u> ო | <u></u> | <u> </u> | - | | <u> </u> | × | × | × | × | | × | | | 8 | - | - | | <u> </u> | 8 ,7 | | | |
| 4 What is the molecular interrelationship between catabolic and synthetic rates of protein metabolism in unloaded muscles? | What is the molecular interrestabolic and synthetic rate in unloaded muscles? | What is the molecular intercatabolic and synthetic rate in unloaded muscles? | accumulation in muscle cell. What is the molecular intercatabolic and synthetic rate in unloaded muscles? | accumulation in muscle cell: What is the molecular intern: catabolic and synthetic rate: n unloaded muscles? | s? elationship between s of protein metabolism | 5b2 3 | <u>е</u> | <u></u> | | - | | ო | × | × | × | × | | × | | | 8 | , | 7- | - | 3, 7, | œ | | | |
| What is the molecular basis for the effects of unloading on the susceptibility of muscle to injury or damage upon resuming normal weight-bearing states? | | What is the molecular basis unloading on the susceptibi or damage upon resuming ratates? | What is the molecular basis unloading on the susceptible or damage upon resuming retates? | What is the molecular basis inloading on the susceptible of damage upon resuming retates? | for the effects of lity of muscle to injury normal weight-bearing | 5b7 3 | N | <u>N</u> | N | | - | ო | × | × | × | × | | × | | | N | + | - | - | 3, 7, | œ | | | |
| | | | | | | | \mathbf{I} | \mathbf{I} | 1 | $\left\{ \right.$ | - | |] |] | 1 | 1 | | 1 | 1 | 1 | 1 | ٦ | ٦ | | | | | | _ |

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

| C1 C2 C3 C4 C5 Critical Qu | C4 C5 Critical Qu | t C5 Critical Qu | 5 Critical Qu | Critical Qu | | s t# | - | | е, | 4 , | 20 7 | | | | - | = | - | 13 | 4 | 151 | ø | 17 18 | | Group w/ | | other D | Disc |
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| What are the similarities and differences of ground-based models and spaceflight-induced bone and connective tissue loss with respect to | 4 | What are the similarities and differ ground-based models and spaceflig and connective tissue loss with rest | What are the similarities and differ ground-based models and spaceflig and connective tissue loss with rest | What are the similarities and differ ground-based models and spaceflig and connective tissue loss with rest | euoq p | 505 | <u>ო</u> | <u>ო</u> | | - | | ო | ^ × | <u>×</u> × | × | | × | | | N | | | <u> </u> | | | | |
| biomechanical, histomorphometric, biochemical and hormonal changes? | | biomechanical, histomorphometric, and hormonal changes? | biomechanical, histomorphometric, and hormonal changes? | biomechanical, histomorphometric, and hormonal changes? | biochemical, | | | | | | | | | | | | | | | | | | | | | | |
| What are histomorphological and architectural changes that occur in bone and connective tissue | | What are histomorphological and archanges that occur in bone and connuctants of snace-flinh? | What are histomorphological and archanges that occur in bone and connucian of eneral linh? | What are histomorphological and are changes that occur in bone and connected to the control of t | | 5c7 3 | е 2 | 8 | 7 | - | - | က | × | <u>× </u> | <u>×</u> | | × | | | N | <u>-</u> | | ო | , , | _ | | |
| Which endocrine-receptor perturbations modulate tissue responsiveness to mechanical stresses? | | Which endocrine-receptor perturbation tissue responsiveness to mechanical | Which endocrine-receptor perturbation tissue responsiveness to mechanical | Which endocrine-receptor perturbation tissue responsiveness to mechanical | | 5d4 | е В | 0 | _ | - : | | က | × | × | × | | × | | | - | | | 4, | | | | |
| Which specific models predict bone and connective tissue structural transients during altered load environments? | | Which specific models predict bone ar tissue structural transients during alternationments? | Which specific models predict bone ar tissue structural transients during alte | Which specific models predict bone ar tissue structural transients during alte | tive | 595 | 9 | 01 | - | | - | က | × | ^ | × | × | × | | | - | - | | | | | | |
| ls cytokine production and response to cytokine osteoblasts and osteoclasts affected by exposu | | Is cytokine production and response to osteoblasts and osteoclasts affected by | Is cytokine production and response to osteoblasts and osteoclasts affected by | Is cytokine production and response to osteoblasts and osteoclasts affected by the misrogravity? | e ē | 5d10 | ю | 8 | 0 | - | _ | ო | × | × | × | <u>×</u> | × | | | 8 | - | - | | 9 | | | |
| 4 Are precursor cells of osteoblasts and osteoclasts affected by microgravity? | | | Are precursor cells of osteoblasts and affected by microgravity? | Are precursor cells of osteoblasts and affected by microgravity? | | 5d11 | <u>м</u> | 7 | 8 | - | _ | က | × | × | × | × | × | | | - | - | | | . 10 | | | |
| Do precursor bone cells respond to maturation stimuli in a microgravity environment as they or earth? | | | Do precursor bone cells respond to ma stimuli in a microgravity environment a | Do precursor bone cells respond to ma stimuli in a microgravity environment a | 유 | 5d12 | m | 2 | 7 | T** | | ၉ | × | × | × | <u>×</u> ~ | × | | | - | - | | | , | | | |
| Do osteoblast require gravity to function normally? If developed in microgravity will the function normally? | | | On each in the control of the contro | or sautification of the control of t | θý | 5d13 | 8 | 2 | - 8 | | | ဗ | × | × | × | × | <u>×</u> | | | - | - | | | 10 | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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11=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Paralle//Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

| Changes in the processing of signals Changes in the processing of signals Semicircular canals or otolith organs that adaptation? Do these changes thate in the vestbular nuclei, cerebellar or other related brainstem and cortical ? What is the time course of such and do they correlate with space motion oral release can be correlated with space astates? What are the states of gaze and eye-head coordination not visual, vestbular, and not visual, vestbular, and not visual, vestbular, and and states? What are the are control the autonomic and endocrine not visual, vestbular, and not visual, vestbular, and not visual, vestbular input lead to changes in ange in vestbular input lead to changes in ange in vestbular input lead to changes in not visual, vestbular input lead to changes in ange in vestbular input lead to changes in ange in vestbular input lead to changes in not visual, vestbular input lead to changes in ange in vestbular input lead to changes are most for 4 3 3 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | Guest# Cr 1 Guest# Cr 1 <t< th=""><th></th><th>15 16 17 18 Group w/ other Disc</th><th>1 1 3, 8, 10</th><th></th><th></th><th>1 1 3, 7, 8</th><th>1 1 3, 4, 8 -</th><th>1 1 3,8</th><th>1. (9. 00.</th><th>1 3.8</th></t<> | | 15 16 17 18 Group w/ other Disc | 1 1 3, 8, 10 | | | 1 1 3, 7, 8 | 1 1 3, 4, 8 - | 1 1 3,8 | 1. (9. 00. | 1 3.8 |
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

Table 4

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| 2 | 3 | 1 | C3 C4 C5 Critical Question | Quest# | 2-1 | 2 | ၉ | 4 | 2 | 9 | <u> </u> | 6 8 | 一 | 0 | 1 12 | 13 | 14 | 15 | 16 | 171 | 8 | rout | Group W/ | other | r Disc | o l |
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| ان د | ဗ | | How does gravity affect the regulation of | 8Vb1 | ъ | N | _ | - | - | ဇ | × | `` | × × | <u>×</u> | <u>×</u> | | | | <u>-</u> | <u>-</u> | | • | | | | |
| <u> </u> | | | metabolism,? Basal metabolic rate? Energy, metabolism, storage and substrate utilization? | | | | | | | | | | | | | _ | | | | | | | | | | |
| | | | Body composition (fat and protein metabolism)? | | | | | | | | | | | | | | | | | | | | | | | |
| , N | | | How does microgravity affect the function | 8Vb4 | 3 | _ | <u>~</u> | က | Q | е | × | × | × × | | × | | | _ | _ | <u>-</u> | <u>-</u> 4 | _ | | | | |
| - | | | including feeding behaviors of gastrointestinal function? | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | 4 | 4 | How does gravity interact with other | 8Vb10 | 3 | <u>-</u> | - | - | 2 | က | × | × | × | × | × | | | _ | _ | - | | | | | | |
| | | | environmental factors to control regulatory | | | | | | | | | | | | | | | | | | | | | | | |
| | | | physiology and behavior? | | | | | | | | | | | | | - | | , | , | | | | o | | | _ |
| 2 | 3 | | What are the transduction mechanisms that couple | 8VI7 | ج. ج. | <u>د.</u> | <u>۰</u> ۰ | <u>~</u> | ٠. | ٠. | × | × | <u>×</u> ×_ | _ | <u>×</u> | | | _ | - | _ | '' - | ν, , | 0 | | | |
| | - | | mechanical stress to musculoskeletal mass and | | | | | | | | | | _ | | | _ | | | | | _ | | | | | _ |
| | | | strength? What are the activation and force | | | | | | | | | | | | | | | | | | | | | | | |
| | | - | development processes of muscle and bone cells? | | _ | | | | | | | | _ | | | | | | | , | | | | | | |
| | | | Do we need artificial gravity countermeasures to | 12 1 | ъ <u>т</u> | _ | 8 | _ | _ | | × | × | <u>×</u> × | <u>×</u> _ | <u>×</u> | | | _ | N | _ | <u>`</u> - | ν, υ | ٥ | | | |
| | | | protect from physiological deconditioning of a | | | | | | _ | | | | | | | | | | | | | | | | | |
| | | | mission to Mars? | | | | | - | | | | | | | | | | | | | | | | | | |
| 2 | | | How should artificial gravity be applied in terms of | 12 2 | 3 | <u>e</u> | N | _ | _ | _ | × | × | ^ × | × × | <u>×</u> | | | | 7 | _ | _ | ν, ω | ٥ | | | |
| | | | g-load, rotation rate, and intermittent versus | | | | | | | | | | | _ | | | | | | | | | | | | |
| | | | continuous exposure? | | | | | _ | | | | | | | | | | | | | | | | | | |
| ٠, | | 4 | What are the effects of intermittent and variable | 2a2 | 4 | 2 | <u>ო</u> | 8 | 8 | ო | × | × | × | × × | <u>×</u> _ | | | _ | | _ | _ | v. V | 9 | | | |
| | | | gravity fields on circadian rhythms, and how does | | | | | | | | | | | - | | _ | | | | | | | | | | _ |
| | _ | | this affect the use of artificial gravity as a | | _ | | | | | | | | | | | | | | | | | | | | | _ |
| | _ | | countermeasure to microgravity? | | | | | | | | | | | | | | | , | | , | , | | u | 1 | | |
| 2 | ო | 4 | What are the effects of non-gravity-related | 2a9 | 4 | 2 | <u>ო</u> | 0 | _ | က | × | × | × | × | <u>×</u> _ | | | | _ | | _ | i, | ń | , o | | |
| | | | physical-chemical and psychological | | | | | | | | | | | | | | | | | | | | | | | |
| | | | space-flight-induced stressors on circadian | | | | | | | | | | - | | | _ | | | | | | | | | | |
| | | | rhythms and sleep? | | | - | ┥ | \dashv | _ | _ | | | ٦ | 7 | ┥ | ┥ | 4 | ┙ | ╛ |] | | ١ | ١ | Ì | | 7 |

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

Table 4

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| , | Quest# | 2a12 | 2d5 | | 2d6 | 2 0 2a | 2g4 | 367 | | 565 |
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| i | | _ | What are the relationships between the stressors associated with space flight; the source, duration and magnitude of the stressor; and decreased immune function? | ە م | /or I'd | What are the effect of changes in cell and nutrient turnover during space flight on nutritional requirements? | | . <u>s</u> | the relationship, if any, between the pulmonary adjustments to space flight and those occuring in Earth-based models such as bedrest, immersion, and head-down tilt? | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in response to unloading? |
| | | What are the effects of cephalad fluid shifts on circadian rhythms? | ess urai | | and e th ega | الم | | ter t of haj | narı) ring rsio | ر مود |
| | | Ë | str 9, d eas | Are there effective operational procedures intermeasures to counteract the stressors reflects? | duc h | ह्न द | | Ther X | DE Z | .≂ .e. |
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| ı | 5 | çis | What are the relationships between the stress associated with space flight; the source, dure and magnitude of the stressor; and decreased immune function? | — Are there effective operational procedures countermeasures to counteract the stressors their effects? | Are there terrestrial (1 g) human, animal and/or computer models that simulate or reproduce the effects of space flight/microgravity with regard to the immune system in space? | What are the effect of changes in cell and turnover during space flight on nutritional requirements? | What are the effects of prescribed countermeasures on thermoregulation? | Are there appropriate animal and/or computer models for studying each functional element of pulmonary adjustments to microgravity? Wha | the relationship, if a adjustments to space Earth-based models and head-down tilt? | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in rest to unloading? |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Altermative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 22 | ၁ | <u> </u> | C2 C3 C4 C5 Critical Question | Quest# | C r | - 2 | 9 | 4 | 2 | 9 | 7 | 8 | 6 | 101 | - | 2 13 | 14 | 15 | 16 | 17 | 18 | Group w/ | | other [| Disc |
| د د | 4 | | What are the circuitry and signals in the vestibular nuclei and brainstem that generate a gravito-inertial frame of reference? What are the roles of the different regions of the cerebellum? | 6a2a | 4 | 4 | | - | - | 2 | × | × | × | × | × | | | - | - | - | 8 | 8, 10 | | | |
| N | | · · · | What is the distribution of receptors for anti-motion sickness drugs in central vestibular pathways? | 6a6 | 4 | <u>ဗ</u> | N | N . | _ | N | × | × | × | × | × | | | - | _ | | | 4, 8, | 10 | | |
| ٠ د | 4 | | What is the most appropriate three-dimensional model of the angular and linear VOR and of central vestibular processing that will account for alterations in eye movements in microgravity? | 6b1b | 4 | е 8 | - | N | _ | 8 | × | × | × | <u>×</u> | × | | | _ | - | | - | က် ထံ | 0 | | |
| * | 4 | | What models of sensory-motor transformation can be used to predict motor behavior best in attered gravitational states? | 667 | 4 | 2 | | m | - | 8 | × | × | × | × | × | | | - | _ | <u> </u> | - | ဗ် | 10 | | |
| <u>ต</u> | | | How are the following cell functions influenced by gravity and/or affected by microgravity: the expression and regulation of genetic information; cell division; cell differentiation; signal transduction, including signal-membrane interactions, membrane-effector interactions, and signal-effector linkage; membrane dynamics; intracellular transport; secretion; alternate pathway regulation; and cell-fo-cell | 811b3 | 4 | _ | | - | N | м | × | × | × × | × | × | | | - | - | - | - | _ | | | |
| | | | communication? The importance of selecting cells and cell lines that can provide interpretable results bearing on precise questions cannot be overemphasized. | | | | | | | | | | | | | | | | | | | | | | |

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | Critica | How will altered gravitational fields and vectors change the information content of the three-dimensional microenvironment of the cells (strome and matrix connections)? How does microgravity affect these signals under both homeostasis and challenge? Representative challenges would be wounding of dermal fibroblas and keratinocytes (or epidermal/dermal wounding in vivo), differentiation of microvessel endothelicells in vitro (or growth of the microvasculature in vivo, particularly following wounding or tumo implantation), and application of stress to active osteoblasts (or bones in vivo). | How I gravit hese | Whay occur issue i | Wha cells t an und | Mha aud neur his |
| | 35 Critica | How will altered gravitational fields and vectors change the information content of the three-dimensional microenvironment of the cells (stroma and matrix connections)? How does microgravity affect these signals under both homeostasis and challenge? Representative challenges would be wounding of dermal fibroblast and keratinocytes (or epidermal/dermal wounding in vivo), differentiation of microvessel endothelial cells in vitro (or growth of the microvasculature in vivo, particularly following wounding or tumor implantation), and application of stress to active osteoblasts (or bones in vivo). | How long can single cells cope with changes in gravitational force without adverse results? Do these effects persist after return to unit gravity? | What structural and morphometric alterations occur in the extracellular matrix, the connectivitissue, and the musculoskeletal systems in long term spaceflight? — How will this result in altered differentiation cells, and in changed tissue composition? | What are the subcellular mechanisms whereby hair cells transduce acceleratory information, amplify it and bring about signal transmission? Is there a fundamental mechanism that is true across the animal kingdom? | What is the role of gravity on sensory thresholds (audition, visual, taste, pain)? How do endocrine, neurohumoral, and metabolic mechanisms influence this effect? |
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | Question Quest# C | in 8Vb7 | 8VI2 4 | 9/16 | 261 | What are the effects of microgravity on renal 2f4 1 1 function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | | 9e 3b3 1 |
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| | Quest# C | y in 8Vb7 | 8VI2 4 ion to d actions? | 8V16 | What are the effects of space-induced endocrine changes on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | jo . | 3b3 1 |
| | C4 C5 Critical Question Quest# C | What role do endocrine and neural systems play in 8Vb7 controlling/modifying adaptation to gravity? | What are the systemic, local, cellular, and 8V12 4 subcellular mechanisms involved in adaptation to altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | What are the biochemical pathways responsible for 8V16 synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to altered gravity? | What are the effects of space-induced endocrine 2b1 danges on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? | Which pulmonary life support procedures should be 3b3 used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? |
| | Question Quest# C | y in 8Vb7 | 8VI2 4 ion to d actions? | 8V16 | What are the effects of space-induced endocrine 2b1 danges on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? | Which pulmonary life support procedures should be 3b3 used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? |

Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| _ | Treatment of medical problems of spacecraft inn temperature, and adverse effects of the gaseous environment? | What are the risks for bubble formation and clinical decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? | Does the atrophy from unloading make muscle, tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | What potential risks does bone loss present to the development of bone fractures, hypercalcemia, metastatic calcification, and renal stone formation? | What is the nature of space flight-induced chan in effect of vasoactive drugs? | What is the nature of space flight-induced effer pharmocokinetics of drugs? | What are the effects of space flight and/or EVA of thermoregulation processes and heat exchange? | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | Does the extent of adaptation affect postflight orthostatic tolerance? | Since microgravity atters blood pressures and flows to some tissues, what are the structural a functional consequences in these various tissues and organ systems with long-duration flights? |
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| | Question Quest# C | What is the effect of long-duration space flights on 4b3 2 the human immune system? (Reg. Physiol see p. 6) | well does injured muscle 5a10 2 | 2 | 8Vb9 2 | Are there in-vitro tests that reliably predict 2d3 3 decreases in immune function in space flight? | How long do neutrophilia, lymphocytopenia, 2d9 3 monocytopenia, eosinopenia, and reduced blastogenic responses persist after flight? |
| | Question Quest# C | What is the effect of long-duration space flights on 4b3 2 the human immune system? (Reg. Physiol see p. 6) | How completely and how well does injured muscle 5a10 2 repair in microgravity? | S What are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can altered gravities affect fertilization, and do these results indicate more general mechanisms of membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? | 8Vb9 2 | Are there in-vitro tests that reliably predict 2d3 3 decreases in immune function in space flight? | How long do neutrophilia, lymphocytopenia, 2d9 3 monocytopenia, eosinopenia, and reduced blastogenic responses persist after flight? |
| | Question Quest# C | 3 * 4 What is the effect of long-duration space flights on 4b3 2 the human immune system? (Reg. Physiol see p. 6) | How completely and how well does injured muscle 5a10 2 repair in microgravity? | What are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen beits? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can attered gravities affect fertilization, and do these results indicate more general mechanisms of membrane atteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? | How does gravity affect compensatory 8Vb9 2 mechanisms (e.g. endocrine, organ, circulatory, regenerative processes)? What is the interaction with growth stages? What is gravity's effect on wound healing? | 2d3 3 | 249 3 |
| | Quest# C | What is the effect of long-duration space flights on 4b3 2 the human immune system? (Reg. Physiol see p. 6) | How completely and how well does injured muscle 5a10 2 repair in microgravity? | what are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can altered gravities affect fertilization, and do these results indicate more general mechanisms of membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? | How does gravity affect compensatory 8Vb9 2 mechanisms (e.g. endocrine, organ, circulatory, regenerative processes)? What is the interaction with growth stages? What is gravity's effect on wound healing? | 4 Are there in-vitro tests that reliably predict 2d3 3 decreases in immune function in space flight? | How long do neutrophilia, lymphocytopenia, 2d9 3 monocytopenia, eosinopenia, and reduced blastogenic responses persist after flight? |

Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| Question Quest# | 264 | 2011 | and magnitude of fluid 2f1 compartment volumes ypogravity and during | What are the time course and magnitude of the diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | 3 b 2 | What is the role of gravity on thirst and feeding 8Vb3 behaviors (appetite, taste preference, and thresholds)? | What are the mechanisms inducing the acute loss of 217 fluid and electrolytes in microgravity? |
| Question Quest# | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space flight? | Does space flight alter gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | *4 What are the time course and magnitude of fluid shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during return to 1 g after flight? | What are the time course and magnitude of the 2f6 diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | hin the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations, particle size profiles, and bacterial contaminations? Do these factors constitute a health hazard? | • 5 What is the role of gravity on thirst and feeding 8Vb3 behaviors (appetite, taste preference, and thresholds)? | 4 * What are the mechanisms inducing the acute loss of 217 fluid and electrolytes in microgravity? |
| Question Quest# | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space flight? | Does space flight alter gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | and magnitude of fluid 2f1 compartment volumes ypogravity and during | What are the time course and magnitude of the diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | 3 b 2 | What is the role of gravity on thirst and feeding 8Vb3 behaviors (appetite, taste preference, and thresholds)? | 3 4 * What are the mechanisms inducing the acute loss of 217 fluid and electrolytes in microgravity? |
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Table 4 Critical Questions That Would Utilize Spacelabs

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| - | | For the well documented changes in calcium metabolism associated with space flight, what the direct and indirect consequences for elect mechanical, and vascular events in the heart? | Does space flight affect pulmonary aging or disease processes commonly found in adults in a 1-g environment? How is subclinical pulmonary pathology (e.g., incipient bronchospasm, early emphysema) affected by space flight? Do these same questions apply to healing processes in the lung? | the ivice | t e | any assa to to /ity, | ophy Ire (vas vas ulter nce: | the amik |
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| | .≍ | 두 음 등 뜻 | Does proces enviro pathol emphy same lung? | What are the acute and long-term effects of the space environment on sleep architecture, quantity and quality? | What are the mechanisms regulating thirst and electrolyte appetite during space flight? | What, if any, are the cardiovascular morpholo changes associated with acute or long-term exposure to space flight (e.g., effects of microgravity, radiation, or environmental haz in the spacecraft)? | Boes atrophy of smooth muscle in the leg vasculature occur during long-term space flight? How are vascular endothelial structure and function altered by such exposure and what are toonsequences? | What is the nature of the interplay between hemodynamic and electrophysiological responses space flight and how much of this is reflex mediated? |
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| | 4 | What is the nature of microgravity-associated changes in the autoregulatory mechanisms of | 3a24 | 4 2 | OI. | е | - | - | 7 | | × | × | × | | | | 12 | - | - | - | | | | Ţ |
| | | arterioles, venules, and lymphatics? What role do these changes play in the adaptation to | • | | | | | | | | | | | | | | | | | | | | | |
| | • | microgravity and return to normal gravity? | 7000 | | | | C | | , | | > | | | | | | | | | | | | | |
| | <u> </u> | space flight affect pH, PO2, or PCO2 in tissues of any organs and vice yersa? | 29K/ | ? + | † | n | <u> </u> | | _ | | < | < . | | | | | V | | | | · · · · · · · · · · · · · · · · · · · | | | |
| | 4 | Are there cellular and subcellular changes in | 3a28 | 4 | <u>ო</u> | က | | ო | ო | × | × | × | × | | | | 7 | | | | 5 | | | |
| | | myocardial contractile proteins? Is there a change in excitation-contraction counting mechanisms | | - | | | | | | | | | | | | | | | | | | | | - |
| | | induced by space flight? | | | | | | | | | | | | | | | | | | | | | | |
| - | 4 | What are the uses of microgravity for better understanding of cardiovascular function on Earth? | 3a29 | 4 | <u>z</u> | <u>ε</u> | <u>¥</u> | <u>£</u> | 2 | × | × | | | × | × | - | _ | | | | | | | |
| | 4 | What are effects of weight bearing on development? | 5a11 | -2 | <u>ო</u> | ო | | - | ဗ | × | × | × | × | × | × | | | | | | · · · · · · · · · · · · · · · · · · · | | | |
| | 4 | What is the role of thalamo-cortical systems in generating a gravito- inertial frame of reference? | 6a2b | 4 | _ | က | 8 | - | 8 | × | × | × | × | | | | | <u> </u> | _ | | ω, | 10 | | |
| N N | 4 | What neuronal models can be used to understand central processing and adaptation in attered | 6a4 | 4 | <u>ო</u> | N | 8 | _ | N | × | × | × | × | × | × | | | | - | | φ. | ო | | |
| м М | 4 | At what sites do signals from the different receptors involved in gaze, body orientation, posture and motion converge? What are the | 6a5 | 4 ω | <u>N</u> | ო | α | <u> </u> | ~ | × | × | × | × | × | × | | - | | - | | က် | ω | | |
| ю | 4 | characteristics of this convergence? Does altered gravity lead to changes in neural control of biological rhythms, such as sleep, and temperature? | 6a7 | 4 ω | <u></u> | - 0 | 0 | - | N | × | × | × | × | | × | | | | _ | | <u>ෆ්</u> | œ | | · · · · · · · · · · · · · · · · · · · |
| e B | 4 | What changes are produced in the visual system by altered states of gravity? | 6a8 4 | 4 | 2 | 2 | ဗ | | 2 | × | × | × | × | | × | | | | - | | က် | œ | | |

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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Table 4 Page 32

Table 4 Critical Questions That Would Utilize Spacelabs
Listed by Category and Criticality

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| | Critical Question | What are the psychophysical correlates and neuribasis for perception of motion? | What are the structure-function relationships of the otolith organs and canals, including development, plasticity, and degeneration? | What are the biophysical and physiological mechanisms of vestibular hair cell transduction and the physiology and pharmacology of transmission? | If single cells sense changes in gravity directly, what are the intracellular structural/functional mechanisms that are sensitive to gravity perturbation? Is the cytoskeleton organization of cells disturbed by gravity perturbation? How does the cell's cytoskeleton, outer membrane and nuclear envelope/nuclear matrix react to altered gravity, as a three-dimensional continuum of perception and structural integrity? | If single cells are too small to detect changes in t gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? |
| | C5 Critical Question | What are the psychophysical correlates and neu basis for perception of motion? | What are the structure-function relationships of the otolith organs and canals, including development, plasticity, and degeneration? | | | If single cells are too small to detect changes in gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? |
| | C4 C5 Critical Question | 4 • What are the psychophysical correlates and neuribasis for perception of motion? | 4 * What are the structure-function relationships of the otolith organs and canals, including development, plasticity, and degeneration? | 4 • What are the biophysical and physiological mechanisms of vestibular hair cell transduction and the physiology and pharmacology of transmission? | If single cells sense changes in gravity directly, what are the intracellular structural/functional mechanisms that are sensitive to gravity perturbation? Is the cytoskeleton organization ocells disturbed by gravity perturbation? How do the cell's cytoskeleton, outer membrane and nuclear envelope/nuclear matrix react to alterec gravity, as a three-dimensional continuum of perception and structural integrity? | anges in te the cells' nvective |
| | C3 C4 C5 Critical Question | What are the psychophysical correlates and neu basis for perception of motion? | | | | gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? |
| | C1 C2 C3 C4 C5 Critical Question | 4 * What are the psychophysical correlates and neu basis for perception of motion? | | 4 | | 4 * If single cells are too small to detect changes in gravitational field directly, what are the environmental changes responsible for the cells' response? Is the cessation of microconvective currents at microgravity responsible? |

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | | If multicellular systems are necessary for gravity sensing, how is this effected? What cellular structures and processes that extend across several cells might be involved? What aspects of cell-cell communication are affected? Would the requirements for cellular interaction/assembly increase sensitivity to indirect or environmentally mediated effects (e.g., reduction of cell-cell and cell-surface contact by dispersion of cells in microgravity)? | what are the mechanisms involved in the transduction of the stimulus of altered gravitational force to a cellular response? By what pathways is the perception of altered gravity relayed intracellularly and/or extracellularly? | How does gravity affect organogenesis and the development of anatomical structures? — Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular, musculoskeletal) of young and adult animals similarly sensitive to this stimulus in ontogeny? | nizing 2a5 rsonnel nce of work- | 5 * What are the long-term effects of the space environment on the interaction between the circadian system and ultradian and infradian rhythms, especially reproductive systems? |
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | C r 1 | d 2b2 to and | 263 | 5p4 | 2c2 space | 2c5 noietin ty? | 2c6 | result from an | roliferation tion, sell death, or | ct 2c7 |
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| | Question Quest# Cr11 | d 2b2 to and | 263 | 2b4 totion, the parrier, and the les? | 2c2 space | 2c5 noietin ty? | 2c6 | ction or survival? | ment of the red blood cell proliferation ss or to differential margination, cell death, or mechanisms? | ct 2c7 |
| | Question Quest# Cr11 | d 2b2 to and | 263 | 2b4 totion, the parrier, and the les? | 2c2 | 2c5 noietin ty? | 2c6 | oduction or survival? - Does the loss of red cell mass result from an | npairment of the red blood cell proliferation coess or to differential margination, ticuloendothelial sequestration, cell death, or her mechanisms? | ct 2c7 |
| | Critical Question | d 2b2 to and | What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | How does space flight affect the pharmacodynamics of hormone action, the permeability of the blood-brain barrier, and the action and metabolism of hormones? | 2c2 | * What is the relationship between altered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | 2c6 | production or survival? — Does the loss of red cell mass result from an | impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? | ct 2c7 |
| | Critical Question | 5 * What are the hypothalamic-pituitary-adrenal and 2b2 opioid system responses to normal space-flight events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, and environmental stimuli? | 5 * What are the acute and chronic effects of space 2b3 flight on endocrine system homeostasis and responsiveness? | 5 * How does space flight affect the pharmacodynamics of hormone action, the permeability of the blood-brain barrier, and the action and metabolism of hormones? | 202 | 2c5 noietin ty? | 5 * What are the major factors and associated 2c6 mechanisms that contribute to the "anemia of space flight"? What controls the alterations in red cell | production or survival? — Does the loss of red cell mass result from an | impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? | 5 * Is the "anemia of spaceflight" related to a direct 2c7 effect of microgravity or other space-flight-induced stressors on bone marrow structure, function, or cellular interaction? |
| | Critical Question | d 2b2 to and | What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | How does space flight affect the pharmacodynamics of hormone action, the permeability of the blood-brain barrier, and the action and metabolism of hormones? | 2c2 | * What is the relationship between altered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | 2c6 | production or survival? — Does the loss of red cell mass result from an | impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? | ct 2c7 |
| | C3 C4 C5 Critical Question Quest# Cr11 | 5 * What are the hypothalamic-pituitary-adrenal and 2b2 opioid system responses to normal space-flight events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, and environmental stimuli? | 5 * What are the acute and chronic effects of space 2b3 flight on endocrine system homeostasis and responsiveness? | 4 5 * How does space flight affect the pharmacodynamics of hormone action, the permeability of the blood-brain barrier, and the action and metabolism of hormones? | 5 * What are the time courses and magnitudes of 2c2 changes in the erythropoietic system during space flight? | 5 * What is the relationship between altered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | 4 5 * What are the major factors and associated 2c6 mechanisms that contribute to the "anemia of space flight"? | production or survival? — Does the loss of red cell mass result from an | impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? | 5 * Is the "anemia of spaceflight" related to a direct 2c7 effect of microgravity or other space-flight-induced stressors on bone marrow structure, function, or cellular interaction? |
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Critical Questions That Would Utilize Spacelabs
Listed by Category and Criticality

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| | | 4 | 2 2 | Are periods of recovery from "anemia of space flight" physiologically analogous to those in subjects who donate blood or otherwise undergo phlebotomy, and can this recovery be accelerated? Does space flight affect the humoral or cell-mediated immune functions, nonspecific immunity, or immune surveillance capabilities of space crews in a manner that would expose them to unacceptable medical risk while on a mission, upon return to Earth, or as a consequence of | 2c8 2d1 | 4 4 | | | | | | × × | × × | × × | × | × | 1 | | - - | | - | | | | | 1 | |
| | | 4 | | I magnitude of in the surface, circulation patterns, cells of the immune numoral, cell-mediated stems? I erwise influence the ost-flight reduction in o nonspecific mitogens the leukocyte count ect to: I ymphopenia, a capacity of natural C differential count, or of immunologically | 292 | 4 | | | | | | × | × | × | | × × | | | | N | N | - | | | | | |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 2 8 | functional capacities of the effector/accessory cells of specific or nonspecific immunity | | - | | | | | | | | | | | | | | | | | |
| 5 ≥ | (monocytes, neutrophils, macrophages, | | | | | | | | | | | | | | | | | | | |
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| ≝ | flight to infectious diseases, allergies, or delays in | | | | | | | | | | | | | | | | | | | |
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| ₹ ₹ | 5 What are the energy requirements of EVA? What is are the effects of deconditioning. EVA. and | 907 | 4 | | | | | | <u><</u> | <u> </u> | < | | | | | | | | 4 | |
| 8 | countermeasures on nutritional requirements and | | | | | | | | | | | | | - | | | | | | |
| 8 | body composition during space flight? | | - | | | | | | | | | | | - | | | | | | |
| ₹ | _ | 297 | 4 | | | | | | × | × | × | | | × | | CI. | _ | N | | |
| ₹ S | study of the effects of space flight on nutrition? | | | | | | | | | | | - | | | | | | | | |
| ₹ | 5 What is the optimal presentation, nutritional and | 269 | 4 | | | | | | × | × | × | | | × | | - | - | _ | _ | |
| 8 | caloric formulation of the diet for maintaining | | | | | | | | | | | | | _ | _ | | | | | |
| ភ | crew health and performance in space flight? What | | | | | | - | | | | | | | | | | _ | | | |
| ភ | are the behavioral and performance responses of | | | | | | | | _ | , | | | | _ | | _ | | | | |
| <u>⊇</u> | individuals to particular food constituents during | | | | | | | | | | | | | | | | | | | |
| S. | space flight? Are there changes in dietary | | | | | | | | | | | | | | | | | | | |
| 죠. ⋅ | | | | | | | | | ; | ; | ; | | | | | | | | • | |
| <u> </u> | ergies | 2010 | 4 | | _ | | | _ | <_ | < | < | | <u> </u> | - | | | | _ | _ | |
| ō | or other abnormal reactions to foodstuffs? | | | | | | | | | | | | | | | | | | | |
| _ | *What are the effects of space-flight-related | 2e12 | 4 | | | | | | × | × | × | × | × | × | | _ | _ | _ | _ | |
| ā | factors, (e.g. bone demineralization and light | | | | | | | | | | | | | | | | | | | |
| g | spectrum) on nutritional requirements? | | | | | | | | | | | | | | | | | | | |
| _≥ | 5 * What changes in carbohydrate/lipid metabolism | 2013 | 4 | | | | | | × | × | × | × | | × | | _ | _ | _ | _ | |
| ŏ | occur during space flight? Are they modified by | | | | | | | | | | | | | | | | _ | _ | _ | |
| 0 | dietary intake? | | | | | | - | | | | | | | | _ | | | | | |

Table 4

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| 5 | ខ្ល | ខ្ល | उ | 剪 | C2 C3 C4 C5 Critical | itical Question | Quest# | ن | - | 2 3 | 4 | 2 | 9 | 7 | 8 | 6 | 100 | Ξ | 12 | 13 | 14 | 15 | 16 | 17 | 18 | S S S | Group w/ | other | Disc |
| | 0 | <u> </u> | 4 | ru. | 5 * Wh | 5 • What are the relationships of fluid and electrolyte responses to space flight on sensory thresholds and space motion sickness? | 2f11 | 4 | <u> </u> | | | | | × | × | × | | <u> </u> | × | | | - | - | 1 | - | | | | l . |
| | | | 4 | ro. | * | *To what extent does the qastrointestinal system modify electrolyte and fluid balance control during space flight? | 2f13 | 4 | | | | | | × | × | × | × | | × | - | 7.7 | - | - | , - | - | | | | |
| - | | | 4 | ις. | * S exc | 5 * What are the compounded effects of microgravity and EVA on thermoregulatory processes and heat exchange? | 282 | 4 | | | - | | | × | × | × | | | × | | | - | - | - | _ | | | | |
| | | | 4 | က | * | How does the regulation of body temperature change during space flight? How do these changes affect the response to thermal load? | 2g5 | 4 | | | | | | × | × | × | × | | × | | | _ | - | + | - | | | | |
| | | 7 | 4 | ιດ | • | *How are changes in body temperature or its regulation correlated with metabolic rate and energy expenditure? | 2g6 | 4 | | | " | | | × | × | × | × | | × | - | | _ | - | - | - | | | | |
| | N | | 4) | 'n | | * How does space flight affect central and/or peripheral thermoregulatory mechanisms? | 297 | 4 | | | | | | × | × | × | | | × | | | - | - | | _ | | | | |
| N | 01 | 4 | | co. | * | * Does a change in otolithic and proprioceptive activity function play a role in regulating calcium or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | 999 | 4 | - | | | | | × | × | × | × | × | × | | | _ | - | | - | 4 , 7 | | | |
| 0 | <u> </u> | 4 | | ហ | Prox otoli card | 6 How do neural mechanisms regulate homeostatic processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | 809 | 4 | | | | | | × | × | × | × | × | | | | - | - | - | - | 4, ռ, | 0 | | |
| N | | | 2 | 'n | * What proc | What perceptual and performance changes are produced by drugs used in treatment of motion sickness? | 909 | 4 | | | | | | | × | × | | × | | | | - | - - | | - | ထ က် | | | |

Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

| 0 | 22 | 8 | 20 | SS | C1 C2 C3 C4 C5 Critical Question | Quest# | C r 1 | 2 | 8 | 4 | 5 6 | 1 2 | 00 | 6 | 10 | = | 12 | 13 | 14 | 15 | 16 | 171 | 8 | Group | × | other | Disc |
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| | | | 3- | ٠ <u>.</u> | 5 What are the mechanisms that underlie gravity perception? | 8la1 | 4 | | | | | × | × | × | × | | | | | - | 2 1 | | _ | | | | |
| | | | Ω. | * 'O | 5 * What are the sequential events in gravity transduction and response? | 8la2 | 4 | | | | | <u>×</u> | <u>×</u> | <u>×</u> | × | - | | | | - | ر 1 | - | | | | | |
| | | | 2 | ۍ ب | 5 * How does a single cell sense gravity? | 8la3 | 4 | | | | | <u>×</u> | $\frac{\times}{\checkmark}$ | $\frac{\times}{\mathbb{Z}}$ | × | | × | | | - | 2 | 2 | - | 0 | | | |
| | | | r) | ro. | 5 • What changes in the routes of perception, transduction and response occur in microgravity? | 8la5 | 4 | | | | | <u>×</u> _ | <u>×</u> | <u>× </u> | × | | | | | - | 7 | - | | | | | |
| | | | ις. | * | 5 * What are the effects of the space environment on membranes and transport during uptake and secretion? | 8103 | 4 | | | | | <u>×</u> | <u>×</u> | × | × | | × | | | - | 0 | 0 | | 10, 12 | 0.1 | | |
| <u> </u> | | | S. | ÷. | 5 * What are the mechanisms by which transport systems are polarized in plants grown in space? | 81c6 | 4 | | | | | <u>×</u> | × | × | × | × | × | | | _ | N N | 2 | - | | | | |
| - | - 11 | | ιΩ | * .vo | 5 • Do single cells sense alterations in gravity directly, in which cells are part of a gravisensing organ, or indirectly, in which the cells detect indirect consequences of the presence or absence of inertial acceleration? | 8 a4 | 4 | | | | | × | × | × | × | × | | | | - | N | 2 | 4, | ທີ່ | 7, 7, | Ξ | |
| | | | ഗ | * V) | 5 * How do the following modifying factors affect gravity "sensing" at the cell level: cell size; cellular dynamics; changes in cell shape; prokaryotic versus eukaryotic cells; adaptive versus non-adaptive cells; circadian rhythms? | 8IIa5 | 4 | | | | | × | × | × | | × | | | | - | N | 0 | 4 | κ | 7, 7, | - | |
| | | | 2 | * 'K | 5 * Research indicates that resting/active cells are not measurably affected by changes in gravity. What is responsible for the difference in responsiveness between resting and active cells? | 811b2 | 4 | | | | | ^ | × | × | × | × | | | | _ | - | - | 4 | - | | | |

Page 40

Critical Questions That Would Utilize Spacelabs

C3 | C4 | C5 | Critical

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10 11 12 13 14 15 16 17 × × × × × × × × თ × × × × œ × × × Criticality × × × ဖ Ŋ Listed by Category and ო Q Quest# Cr1 4 811b4 811b6 8IIc2 8112 responses following the binding of specific growth an independent variable or a quantifier? What are Which developmental mechanisms have evolved to factors to their cognate membrane receptors--as signal transfer, and the nuclear envelope/nuclear multicellular systems affected by microgravity? perturbing cell structure/function in the absence intracellular pathways of chemically mediated How can gravity be used as a research tool in How are cell-cell and cell-surface contacts in How does the gravity stimulus affect cellular the contributions of the cytoskeleton, the matrix to functional response? Question of other effectors?

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4 4 8113 81115 microgravity, disturb the precise coordination and be dependent on the 1-g gravity field and vector? in both environments may be particularly valuable Considering development as a series of stages or phases, beginning with pattern specification, and Those animals which pursue different life stages - Will aquatic animals perceive and respond to Which organ systems are dependent on the 1-g gravity affect selected phases in animals that progressing through differentiation, how will - How will gravitational fields, particularly gravity as do their terrestrial counterparts? represent different species and phyla? postural control required in mating? gravity field and vector? 5 5 *

for study.

1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality

11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| - | 81112 4 | 8IVa2 4 | 81Va3 4 | 8IVc2 4 | 81Vc4 4 | 81Vc5 | 8IVd1 |
| Question Quest# Cr | s gravity produce responses in cultured 81112 in mimic those seen in chronologically aged use isolated from accelerated aging as, and senescent cells in vitro? In de-limiters of lifespan have relevance to base effects? | avity in the evolution of 8IVa2 | rties and fundamental 81Va3 gravity sensors to adapt lent? | ing gravity sensors 81Vc2 ar acceleratory What is the basis of | amental principle of gravity sensor 81Vc4 cessing that permits determination sional (3-D) linear acceleratory the body (in many invertebrates) d in vertebrates? | otoconial or 8IVc5 ory environment, le neural substrate? | 8IVd1 |
| Question Quest# Cr | s gravity produce responses in cultured 81112 in mimic those seen in chronologically aged use isolated from accelerated aging as, and senescent cells in vitro? In de-limiters of lifespan have relevance to base effects? | 8IVa2 | What are the basic properties and fundamental mechanisms that permit gravity sensors to adapt to an altered g-environment? | 81Vc2 | 81Vc4 | 8IVc5 nent, bstrate? | 8IVd1 |
| Quest# C r | s gravity produce responses in cultured 81112 in mimic those seen in chronologically aged use isolated from accelerated aging as, and senescent cells in vitro? In de-limiters of lifespan have relevance to base effects? | 8IVa2 | What are the basic properties and fundamental mechanisms that permit gravity sensors to adapt to an altered g-environment? | 81Vc2 | 81Vc4 | 8IVc5 nent, bstrate? | 8IVd1 |

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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

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| | - | 8IVd5 4 | | | | | | | | |
| | Cr1 | 81745 | 8IVe5 4 | 81Vf2 on ?r | 8Va2 | 8Vb6 | 8Vb8 | 8Vb11 4 | 8Vb12 | 8Vb13 |
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| | Question Quest# Cr1 | and 81Vd5 | 81Ve5 | een 81Vf2 nation ution? | gravity affect interactions between the 8Va2 system and ultradian and infradian | 8Vb6 sms, | exocrine 8Vb8 Transitter | 8Vb11 | If so, how 8Vb12 | 8Vb13 |
| | Question Quest# Cr1 | 8IVd5 | Are there species differences in degree of 81Ve5 susceptibility to a developmental change in an altered-g environment? | *What is the importance of an interaction between 8IVf2 gravity sensor input and other sensory information in total 3-D orientation, over time, of the organism? How does this change during evolution? | * How does gravity affect interactions between the 8Va2 circadian system and ultradian and infradian rhythms? | 8Vb6 hanisms, | e 8Vb8 itter | d 8Vb11 | If so, how 8Vb12 | 8Vb13 |
| | Question Quest# Cr1 | 8IVd5 | Are there species differences in degree of 81Ve5 susceptibility to a developmental change in an altered-g environment? | *What is the importance of an interaction between 8IVf2 gravity sensor input and other sensory information in total 3-D orientation, over time, of the organism? How does this change during evolution? | * How does gravity affect interactions between the 8Va2 circadian system and ultradian and infradian rhythms? | 8Vb6 hanisms, | e 8Vb8 itter | d 8Vb11 | If so, how 8Vb12 | 8Vb13 |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize Spacelabs Listed by Category and Criticality

| 15 | 12/2 | l is | 1 X | C1 C2 C3 C4 C5 Critical Question | Quest# Cr | [C] | 1 | 2 | 3 4 | 1 5 | 9 | 1 | 8 | 6 | 10 | 11 | 12 | 13 | 4 | 151 | 1617 | 7 18 | 3 Group | Group w/ other Disc | r Dis |
|----------|------|----------|-----|--|-----------|-----|---|---|-----|-----|---|---|----------|----------|----------|----|----|----|----------|--------------|--------------|------|---------|---------------------|-------|
| \vdash | + | \vdash | 5 | 5 * Is 24 hour per day 1-g exposure necessary to | 8Vb14 | 4 | | | | | | × | × | × | × | × | | | <u> </u> | <u>-</u> | _ | _ | 4 | | |
| | | - | | maintain normal regulatory function? If not, what | | | | | | _ | | | | | | | | | | | | | | | |
| | | | | is the minimum time? What are the optimal | | | | | | | | | | | | | | | | | | | | | |
| | - | | - | presentation characteristics of the G stimulus? | | | | | - | | | | | | _ | | | | | | | | | | |
| .4 | 8 | | L) | 5 * is the musculoskeletal cyto-architectural | 8VI3 | 4 | | | | _ | | × | <u>×</u> | <u>×</u> | × | × | × | | <u> </u> | - | _ | _ | _ | | |
| | | | | organization and responsiveness to physiological | | | | | | | | , | | | | | | | | | | | | | |
| | | | | and mechanical stimuli attered by gravity? | | | | | : | | | | | | | | | | | | | _ | | | |
| | | | 40 | 5 * Is the relationship between musde and bone | 8VI12 | 4 | | | | | | × | × | × | × | × | × | | | - | _ | _ | 7 | | |
| | | | | necessary for an integrated response to altered | | | | | | | _ | | | | | | | | | - | | | | | |
| | | | _ | gravity or do the systems respond independently? | | | | | | | | | | | | | | | | | | | _ | | |
| | | - | 4) | 5 * Which mechanisms of adaptation of the | 8VI16 | 4 | | | | | | × | × | × | × | × | × | | | 7 | - | _ | _ | | |
| _ | | _ | | musculoskeletal systems of rats, monkeys, and | | | | | | | | | | | | | | | | | | | | | |
| | | _ | | humans to altered gravity are similar and which | | | | | | | | | | | | | | | | | | | | | |
| | | | | mechanisms are different? | | | | | | | | | _ | | | | | | | | | | | | |
| _ | | | 4, | 5 * What is the degree of molecular complexity and its | 11a1 | 4 | | | | | | × | × | × | | × | × | | | 2 | 2 | _ | | | |
| | | | | evolution in circumstellar, interstellar, and | | | | | | _ | | _ | | | | | | | | _ | | | | | |
| | | | | protosolar environments? | | | | | | | | | | | \dashv | _ | | | | \dashv | ᅱ | ᅱ | | | |

TABLE 5

CRITICAL QUESTIONS THAT WOULD UTILIZE SPACE STATION FREEDOM (SSF) LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- 3 = Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- 4 = Science Specifically enabled by Moon and/or Mars Missions.
- 5 = Basic Research Not Directly Applicable to Moon and/or Mars Missions.
- * = Indicates primary category of application.

CRITICALITY

appropriate)

Ground-based

Spacelab

EDO

SSF

No

Program research

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| 1. | Scie | nce Readiness Levels |
|----|-------|--|
| | 1. | Only folkiore of practitioners and anecdotal data available |
| | 2 | Basic scientific concept formulated |
| | 3. | Ground models developed, flight validation required |
| | 4. | Flight validation performed |
| | 5. | Countermeasures identified |
| | 6. | Countermeasures tested |
| | 7. | Operational requirements established |
| 2 | Tech | nology Readiness Levels |
| | 1. | Technology need identified |
| | 2 | Technology and conceptual solution available |
| | 3. | Component and/or breadboard validation in laboratory |
| | | environment exist |
| | 4. | Flight validation performed |
| | 5. | Systems/subsystem prototype demonstration in a relevant |
| | | ground or space environment completed |
| | 6. | System prototype demonstrated in a space environment |
| | 7. | Actual system completed and flight qualified through test and |
| | | Demonstration |
| | B. | Actual system "flight proven" through successful mission |
| | | operations |
| 3 | Sche | dule (information required by) |
| - | 1. | = Near term < 5 years |
| | 2 | = Mid term 6-10 years |
| | 3. | = Far term > 10 years |
| 4 | | Required |
| | 1. | = Substantial |
| | 2 | = Moderate |
| | 3 | - Low |
| 5 | Defin | ed Sequence (Clearly defined sequential path for scientific |
| _ | inves | igation exists) |
| | 1. | - Yes |
| | ž | = No |
| 6. | | eVAlternative Path (are parallel or alternative pathways |
| _ | | and the second of the second o |

Ground-based research required

Spacelab would be used for research

Space Station Freedom would be used

Spacelab needed for Extended Duration Orbiter

| 10. | Centrifu | Q0 |
|-----|------------|---|
| | X | SSF Centrifuge Facility would be used |
| 11. | Free Fly | /er |
| | x | = Free flyer biosatellite |
| 12 | Luner B | 884 · |
| | X | = Lunar base would be used |
| 13. | Robotic | Explorer |
| | X | Robotic explorer would be used |
| 14. | Other R | equirements |
| | X | Requirement for flight resources other then those identified in 8-10 |
| 15. | Flight Va | alidation Required |
| | 1. | Flight validation required |
| | 2 | = Not required |
| 16. | Facilities | Sufficient |
| | 1. | Current ground facilities (NASA Centers, Universitie |
| | | and provide industry) are sufficient. |
| | 2 | Current ground facilities insufficient |
| 17. | Commun | nity Sufficient |
| | 1. | There is a sufficient scientific community already committed or recruitable |
| | 2 | Scientific community is insufficient |
| 18. | Attract N | ew Community |
| | 1. | Activity will attract new scientists |
| | 2 | Activity will not attract new scientists |
| 19. | Group wi | ith other disciplines (can this activity be grouped with |
| | others fro | om different life science disciplines?) |
| | 1. : | No, cannot be grouped |
| | _ | Do not know at this time |
| | | Behavior, Performance and Human Factors |
| | | Regulatory Physiology |
| | | - Cardiopulmonary |
| | | - Environmental health |
| | | - Musculoskeletzi |
| | | - Neuroscience |
| | | - Radiation Health |
| | | Cell and Developmental Biology |
| | | Plant Biology |
| | 12. | Life Support |

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| + 2 | 8 | L | | | What | What factors should be considered (e.g. maintainability, reliability, operator discretion) | 1 1 4 2 | - 2 | 5 | e | - | ю | б | × | × | | | × | | | - | - | - | 2 | | | |
| | | | | | when | when allocating functions between humans and machines? | | | | | _ | | | | | | | | | | | | | | | | |
| * | က | | | | What | What are the acceptable numbers and kinds of microorganisms in air, water, food, and surfaces? | 4b1 | ΓC | ო | N | 2 | - | - | × | × | | | × | | | | - | - | - | 10 | | |
| * | | | | | What | the flux, | 7a8 1 | - 2 | 4 | - | - ! | ო | ო | <u> </u> | × | | × | × | × | | N | ~ | + | - | | | |
| | | | | | energ | energy, and linear energy transfer spectra of the radiation? | • | | ······································ | | | | | | | | | | | _ | | | | | | | |
| * | | | · | | How cosm event | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events be improved? | 7a9 1 | | 8 | ო | • | - | - | × | × | | × | × | × | | 0 | <u>- </u> | | - | | | **** |
| - | | 4 | | | How | e are foods considered for w can storage stability in | 9b11 1 | <u>ო</u> | 9 | - | 3 | - | - | × | <u>×</u> | | | × | | | | - | _ | - | က် က် | 9 | |
| | | | | | sbac - | space be increased? — What are the safety and quality considerations | | | | | | | | | | | | | | | | | | | | | |
| | | | | | ₹ ₹ | of storage? What processes are feasible to use in a CELSS? | | | | | | | | | | | | | | | | | | | | | |
| | | | | | : « | Are additives needed? If so, which ones? | | - | | | | | | | | | | | | | | | | | | | |
| | | | | | > [| What are the storage/inventory requirements? For what types of foods will storage be | | | | | <i>.</i> | : | | | | | | | , | | | | | | | | |
| | | | - | | nun | unnecessary? | | | | | | | | | | | | | | | | | | | | | |
| | | | | | <u>s</u> . | Is there a need for packaging? If so, which | | | | | | | | | | | | | | | | | | | | | |
| | - | \dashv | | | produ | products will require it? | | | | | | | | | \dashv | | \dashv | | _ | | | | | | | | |

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

Table 5

| 5 | 줐 | 8 | 3 | C1 C2 C3 C4 C5 Critical Question | | Quest# | C H | 1 2 | 3 | 4 | 5 | 6 7 | 7 8 | 6 | 19 | 11 | 12 | 13 | 4- | 151 | 19 | 1 | 8 G | Group | | other (| Disc |
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| * - | | | 4 | What food processing and storage technologies will need to be developed for space application? — How will existing and new processing and storage techniques perform in the constraints of a CELSS environment? — What differences are there in product development for space compared to land-based activities? — What are the influences of processing, cooking, and serving on — nutrient and attribute stability? — How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? | | 9912 | - | φ | - | N | - | - | × | × | | | × | | | _ | _ | _ | ю́ | ů, | 0 | | |
| * | | | | What are the processing requirements necessary to handle human wastes? What are the health and safety requirements for the waste treatment subsystem? | | 9c168 | - | 2 | _ | N | N | × | | × | | | × | | <u>-</u> | - 2 | ~ | - | က် | ဖ | | | · n |
| • | | | | Can the physico-chemical regenerative technologies and processes required for a Mars mission life support system function in the space environment? Consider: — Maintenance of liquid-gas interfaces (e.g., for nutrient delivery) — Transfers and separations of liquids, solids, a gases — Combustion What is the composition of air, water, and spacecraft systems and how is it monitored to | or or | 96425 | - | - | - | _ | N | × - | × | × | | 1 | × | | | - | - | _ | 01 | - | ε΄ | 6, 12 | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| | Question Quest# C | er and air be 9f1a Do rovide safe r for the | What requirements should be placed on robotic and 10 1 human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | 5 | 101 | . s | and 4a2 on ixtures der flight |
| | Question Quest# C | Can safe and sufficient supplies of water and air be 9f1a provided for the trip/stay to/at Mars? Do current expendable systems exist to provide safe and sufficient supplies of water and air for the Mars mission? | D 10 1 | 5 | 101 | . s | and 4a2 on ixtures der flight |
| | Quest# C | er and air be 9f1a Do rovide safe r for the | What requirements should be placed on robotic and 10 1 human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | 5 | 101 | What impact do space flight-induced biological, physiologica, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | How can traditional limited-time exposure and 4a2 human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| | virable) | | (air, ' | d the | What are the effects of all potential atmospheric components, including contaminants and factors on physical and psychological well-being and crew performance? | 5 | What are the differences, if any, between species and their tissues in their perception and responses to gravity? | ore | leo f | Is cell, tissue, or organ differentiation affected in microgravity? |
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| <u>≅</u> | What are the effects of chronic exposure to ultrafine and larger (respirable and nonrespingarticles on crew health, safety, and performance? | What is the effect of space flight on all microorganisms? | What technology is available to identify microorganisms in crew and environmental water, surfaces) specimens. How are microorganisms controlled by anti-microbial procedures? | What, if any, are the interactions between the effects of microgravity on crewmembers and teffects of off-baseline levels of atmospheric parameters, including gas composition, pressuand temperature? | What are the effects of all potential atmospheri components, including contaminants and factors physical and psychological well-being and crew performance? | What are the thresholds required for gravity have an effect? | What are than and their tise to gravity? | Can plants successfully reproduce through more than one generation in space? | ls chromosomal integrity and behavior during division affected in microgravity? | ls cell, tissue, microgravity? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| 5 Critical Question | What effect does microgravity have on embryogenesis and the ensuing stages of the life cycle of plants from maturity to flowering and senescence? | Are microgravity-grown tissues and organs competent? | Are the growth rates of higher plants or single cells affected by microgravity? | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered in microgravity? | What effect does microgravity have on the synthesis of storage and support polymers? | Are pathways for plant nutrient absorption altered in microgravity? | What are the effects of the space environment on long distance transport of water and on transpiration? | How is the effect of gravity (and microgravity) or cells influenced by magnetic fields and radiation? |
| | What effect does microgravity have on embryogenesis and the ensuing stages of the licycle of plants from maturity to flowering and senescence? | Are microgravity-grown tissues and organs competent? | Are the growth rates of higher plants or single cells affected by microgravity? | | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered in microgravity? | What effect does microgravity have on the synthesis of storage and support polymers? | Are pathways for plant nutrient absorption altered in microgravity? | | How is the effect of gravity (and microgravity) cells influenced by magnetic fields and radiation |
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| Question Quest# C | Can crop plants produce sufficient edible biomass extra-terrestrially to support human crews? The following constraints should be considered in studying this question: - Closed environments - Recycling - Limited space - Gravity effects - Phytogenic volatile compounds and other trace contaminants - Radiation - Adventitious biota (microbial and other) What conditions are required to optimize the food generating and water recycling capacity of crop plants? The following factors represent the minimum that should be considered in studying this question: - Light quantity, quality, periodicity, gas composition and density - Root environment: substrate, nutrients, volume, temperature, etc Aerial environment: gas composition and pressure, temperature, planting density, etc. | What are the effects of adventitious biota ga4 2 (microbial and other) over long periods in a CELSS? |
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| ti oi | | What is the potential for using the following | alternative food sources in a CELSS? | Animals (aquatic and terrestrial, vertebrate | | | | | Non-traditional higher plants | Tissue-cultured cells | | What are the specific nutritional requirements | humans in space? This question should consider | | Caloric requirements | Will the nutritional requirements of the crew | change and require modified diets over time of | | Fluid requirements | Distribution of the macro nutrients (protein, | <u>ā</u> | Fiber and micronutrient requirements |
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Critical Questions That Would Utilize Space Station Freedom (SSF)

Table 5

Listed by Category and Criticality

| What are the acceptability criteria for foods and in 9b9 2 2 NR 1 2 what priority order should they be evaluated? Some criteria include: - Safety and freedom from toxic substances and infectious agents - How will the crew respond to diet on a Mars mission - Nutrient and attribute balance - Familiarity/cultural experience - Taste/rexture/color/shape - Familiarity/cultural experience - Taste/rexture/color/shape - Familiarity/cultural experience - Familiarity/cultural experience - Compatibility in preparation methods - Compatibility with other menu items - Variety - What food groups fuffill these requirements? - How do the above nutritional questions apply to CELSS produced foods, used either as a nearly complete diet or as a supplement to stored food? 1 To what extent will micro-organisms used in a physico-chemical waste processor present an issue of performance degradation? What are the best technologies for recycling the water required for a Mars mission to accentable | U | | | | | | | | | | | |
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| potable and hygiene levels? | | | | | | |) | | <u> </u> |) | | |
| What are the storage requirements for potable and 9c27 2 2 6 1 2 | 2 - X | × | | × | | _ | 8 | - | က် | 9 | | |
| nygrene water in a CELSS? Consider: — Safety/redundancy | - | | | | | | | | | | | |
| Control of microbial film on surfaces | | | | | | | | | | | | |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality 2 Table

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11=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Plyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Page 1

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | Question | What are the requirements for CELSS system design and operation to achieve safe and reliable operation? Address the following: | | sholds of system size (minimal) and reliability (maximal), and ided in an integrated, controlled | How can mathematical models be utilized to aid in 9d35 system design, system simulation, and system operations? | What sensors are required for automation of a 9d38 CELSS? | What is the productivity, transpiration, and dry 9e39 matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | What is the morphology and reproductive capability 9e40 of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for space hases? |
| | Question | What are the requirements for CELSS system design and operation to achieve safe and reliable operation? Address the following: — Subsystem redundancy - Interaction with Chemical - Physical regeneration — System modeling and behavior — Alternative stratenies for system modification | and control — Failure of a subsystem Is a CELSS, because it operates within a limited volume and intense dynamics, subject to unknown or poorly characterized instabilities, such as | What are the thresholds of system size (minimal) and system safety and reliability (maximal), and can these be extended in an integrated, controlled system? | How can mathematical models be utilized to aid in system design, system simulation, and system operations? | What sensors are required for automation of a CELSS? | What is the productivity, transpiration, and dry matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | What is the morphology and reproductive capability of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for snace bases? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| î | Question Quest# | intermeasures can be utilized if 9e41 2 ity or reproduction is significantly d? | What are the effects of the space environment on 9e43 2 microbial interactions with space systems and humans? | vided 9f1c 2 | | monitor 915a 2 | pabilities 9f6a 2 | What are the optimal environmental conditions for 2a3 3 ensuring synchronization of circadian rhythms in space, and what are the most appropriate | work-rest schedules for ensuring optimal health and performance? | What are the effects of pressure and gas 2f12 3 composition in space flight and during EVA on changes on fluid and electrolyte regulation? | sing 4a5 3 | 2 What is the probability for genetic and 7g5 3 developmental detriment incurred as a consequence of radiation exposure in space? |
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| 20110 | | ity of the | o o | | e nutrient quality and bioavailability natural toxicants e plant architecture foods and/or ingredients be derived dible plant wastes? re the crop plant-specific limits of this |
| 20100110 | | ity of the | What robotic and automated procedures should be developed for planting, growing, and harvesting of crop plants? | How can molecular genetic technology, including germplasm screening, be used to develop crop cultivars better fit for CELSS use in space? (for example) | — Improve nutrient quality and bioavailability — Reduce natural toxicants — Optimize plant architecture Can edible foods and/or ingredients be derived from non-edible plant wastes? — What are the crop plant-specific limits of this capability? |
| | | What is the role of gravity in the regulation of circadian rhythms? — What are the effects of the absence of gravity on the generation, expression (period, phase, amplitude and/or waveform) and entrainment of circadian rhythms? — Is it at the synchronizing agent (zeitgeber)? — If not, is it necessary for the action of other synchronizing agents (light, exercise)? — What is the role of gravity in the ontogeny of circadian rhythms? — Is there a difference in the role of gravity across the phylogenetic scale? Single cells to complex organisms? — What is the gravity threshold for it actions in the regulation of circadian rhythms? Does this gravity threshold vary with the complexity of the organism? | What robotic and automated procedures should be developed for planting, growing, and harvesting of crop plants? | How can molecular genetic technology, including germplasm screening, be used to develop crop cultivars better fit for CELSS use in space? (for example) | — Improve nutrient quality and bioavailability — Reduce natural toxicants — Optimize plant architecture Can edible foods and/or ingredients be derived from non-edible plant wastes? — What are the crop plant-specific limits of this capability? |

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| \$ <u>\$</u> | <u>\$</u> | o ō | to convert metabolic wastes into nutrients suitable for plant growth? | | | | | | | | | | | | | _ | | | | | | | | | |
| <u> </u> | <u> </u> | ≥ | trient | 9c19 | 2 | N | _ | N | α_ | _ | × | × | | | × | | | _ | 8 | | <u>-</u> | ა, ი | | | |
| 2 2 | 2 2 | 97 | regeneration technologies can be adapted to a | | | | | | | | | | | | | | | | | | | | | | |
|) ŏ |) 0 | 5 ~ | developed for space application? (Note question | | | | | | | | | | | _ | | | | | | | | | | | |
| _ | Ξ | _ | 16.8) | | | | | | | | | | | | | | | | | | - | | | | |
| <u>-</u> | | - 5 | What are the production rates and chemical | 9622 3 | 2 | - | _ | _ | 0 | | ^ | × × | _ | | × | | | | 8 | | _ | ω, O | | | |
| 8 | 8 | ℧ | compositions of the different waste streams that | | | | | | | _ | | | | - | | | | | | | | | | | |
| w w | ਕ | æ | are to be processed in a CELSS? | | | • | | | | | | | | | | | | | | | , | | | | |
| 0 | 0 | O | Can plant transpiration water qualify as potable | 9c24 | 3 | - | _ | _ | C۷ | _ | × | ^ | × | - | <u>×</u> | | 1 | ,- | | _ | _ | ა, ი | | | |
| 55 | 5 | 5 | and hygiene water? If not, what currently | | _ | | | | | | _ | | _ | | | _ | | | | | | | | | |
| w. | Ø | Ø | available water treatment technologies can be | | | | | _ | _ | | | | | | | | | | | | | | | | |
| Ď | ă | ď | adapted to polish transpiration water in a CELSS, | | | | _ | | | | | | | | _ | | | | | | | | | | |
| ō | <u>ਕ</u> | ਰ | d what technologies will need to be developed for | | | | | | | | | - | | - | | | | | | | | | | | |
| S | S | S | space application? | | _ | | | | | | | | | | | _ | | | | | , | | | | |
| _= | = | = | meet | 9c25 | 3 | - | <u>-</u> | N | 0 | - | × | × | × | | <u>×</u> _ | | | | N | | _ | ນຸ _ ວ | | | |
| * | * | # | the production rate demands for potable and | | | | _ | | | | | | | | _ | | | | | | | | | | |
| <u> </u> | 2 | 2 | hygiene water, then what types and numbers of | | | | | | | | | | | | | - | | | | | | | | | |
| <u>-</u> | <u> </u> | a | plants will be required, and what environmental | | | | | | | | _ | | _ | | | | | | | | | | | | |
| <u> </u> | <u>.</u> | O | conditions will these plants require? | | | | | | | | | | | | ; | | | | | , | • | | | | |
| _ _ | Ť | _ | What currently available water treatment | 9026 | 3 | <u>ო</u> | - | 7 | 2 | - | × | × | × | | <u>×</u> _ | _ | | | <u>N</u> | | | າ <u>ົ</u> | | | |
| <u></u> | <u> </u> | _= | technologies can be adapted to recycling the | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | various grades of water (hygiene, wash, etc.) in a | | | | | | | | | - | | - | | | | | | | | _ | | | |
| | <u> </u> | | CELSS and what technologies will need to be | | | | | | | | | _ | | | | | _ | | | | | | | | |
| _ | Ť | | developed for space application? | | | | | | | | | | | | | | | , | | • | | | | | |
| 4 | | _ | | 9c30 | 8 | <u>~</u> | <u>-</u> | 7 | 7 | _ | × | × | × | × | <u>×</u> _ | | | | N | | | າ ດ | | | |
| | | _= | required to meet the production rate demands for | | | | | | | | | | | | | | | | | | | | | | |
| | | | revitalized air and what environmental conditions | | | | | | | | | | | | | _ | | | | | | | | | |
| | | | do these plants require? | | | | \dashv | \dashv | 4 | \rfloor | | | ٦ | | ᅦ | \dashv | 4 | ┩ | 4 | 4 | | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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2 Table

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | Ques | | | | | | 5 | 293 | s 5c12 | 189 | 1d1 | | 117 |
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| | Question | ·-> | Can proposed food processing techniques be 9e44 modified to work effectively at reduced gravity? | | Ð | | | What environmental conditions of space flight influence temperature regulation? | What are the appropriate light wave length cycles 5c12 to maximize vitamin D production? | How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? | | human operators, and countermeasures for particular missions? | tting individual and 117 vity during space |
| | Question | | | | | | 5 | | e length cycles | | the | human operators, and countermeasures for particular missions? | tting individual and 117 vity during space |
| | C4 C5 Critical Question | | | | | | 5 | | e length cycles | | the | human operators, and countermeasures for particular missions? | tting individual and 117 vity during space |
| | C4 C5 Critical Question | What robotic and automated procedures should be developed for control, monitoring, and operations? | Can proposed food processing techniques be modified to work effectively at reduced gravity? | | | | What provisions must be taken during the course of 10 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | What environmental conditions of space flight influence temperature regulation? | e length cycles | 4 How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? | What are the factors involved in integrating automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by | human operators, and countermeasures for particular missions? | 3 4 What are the criteria for evaluating individual and 117 crew performance and productivity during space |
| | Question | What robotic and automated procedures should be developed for control, monitoring, and operations? | Can proposed food processing techniques be modified to work effectively at reduced gravity? | Can wastes be successfully disposed of on a Mars mission without impacting planetary protection? | Do regenerative systems exist to provide safe and sufficient supplies of food for the Mars mission? | Do automated systems exist to monitor food safety/quality for Mars mission? | What provisions must be taken during the course of 10 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | What environmental conditions of space flight influence temperature regulation? | What are the appropriate light wave length cycles to maximize vitamin D production? | How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? | What are the factors involved in integrating automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by | human operators, and countermeasures for particular missions? | What are the criteria for evaluating individual and 117 crew performance and productivity during space |

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| 22 | ខ | ঠ | CS | C3 C4 C5 Critical Question | Quest# | C r 1 | 2 | 3 | 4 | 2 | 9 | 7 8 | 8 | - | - | 112 | 13 | 14 | 151 | 9 | | 8 | Group w/ | | other [| Disc |
| 2. | 6 | | | What are the effects of stress on crew and ground | 191 | 1 2 | <u></u> | 3 | 1 | - | e . | × | <u>×</u> _ | | | × | | | - | | | 4 | | | | |
| | | | | team performance and what method of detection and intervention strategies (e.g. selection, training, crew support) would prove effective? | | | | | | | | | | | | | | | | | | · · · · · · · · · · · · · · · · · · · | | | | |
| . 2 | | 4 | | What are specific countermeasures that impact effectively upon bone and connective tissue | 5c3 | - | 2 | α | | _ | ო | × | × | <u>×</u> | _ | <u>×</u> | | | - | - | | | ຕົ | | | |
| 8 | | 4 | | structure and function? Will the decrease in afferent input to the | 691 | | ω_ 4 | | 2 | - | N | × | × × | × | <u>×</u> | × | | | - | - | | | 7, 8, | 9 | | |
| | | | | vestibular, proprioceptive and somato-serisory systems associated with long-duration flights result in permanent reflex deficits? | | | | | | | | | | | | | | | • | | | | | | | - |
| . 2 | | | | What are the critical characteristics of leaders | 1a6 | 8 | <u>z</u> თ | <u>E</u> | 8 | | N | × | | × | | × | | | - | 2 | <u>-</u> | | _ | | | |
| | | | | What are the optimal crew command structures for a Mars mission? | | | | | · | | | | | | | | | | | | , | | | | | |
| 8 | | | | What psychological and behavioral characteristics are exclusary? What behavioral and psychometric criteria should be used for selecting candidates for a Mare mission? | 161 | N | Ν | <u>ო</u> <u>წ</u> | - | ო | ო | × | | × | | × | | | - | N | - | <u> </u> | - | 1 | | <u>-</u> |
| 8 | | | · · · · · · · · · · · · · · · · · · · | What are the protocols for training effective ground teams and space crews in problem solving, | 162 | 0 | <u>е</u> | <u>e</u> | 7 | ო | ო | × | × | × | | × | | | - | 2 | _ | _ | _ | | | |
| | | | | interpersonal dynamics? What are the physical and cognisant performance capabilities and requirements of humans in | 147 | 8 | - | <u></u> | α | 8 | - | × | × | × | | × | | | - | - | - | - | 7, 8, | , 12 | | |
| | | | | different stages of space flight as a function of mission parameters, e.g. duration, gravity field, physical environment? | | | | | | | | | | | <u></u> | > | | | _ | C | • | | c | | | |
| 0 | | 4 | | What are the effects of living in the space flight environment on cognitive functions (including attention, memory, information processing and decision-making) and on work capacity? | 162 | N | - | <u>z</u> | - | - | ო | | × | × | | Χ | | | | N | | | y | | | |
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Table 5

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| 5 | ଧ | ខ | 8 | ర | C1 C2 C3 C4 C5 Critical Question | Quest# Cr | Ę | 2 | <u>ر</u> | 4 | 5 6 | ۲ | F | ٩ | F | = | 13 | 12 | E | H | H | + | F | | | | Γ |
| | . 8 | | 4 | | How do the fundamental behavioral processes of perception and sensation, learning and cognition, and motor skills change in space? What is the time course of adaptation? | 8 | _ | £ | | | 1 | | | T | - | - | - × | 0 | t | n | | | 0 | aroup 8 | × | other | DISC |
| | N | | | | What procedures are needed for analyzing missions 1f for their demands on human performance (e.g. task analytical techniques and models)? | 7 | က | Œ. | m | 8 | - | <u>×</u> | <u>×</u> | <u>×</u> | | | × | - | | | - | - | | | | | |
| - | N | | | | What are the special performance requirements and capabilities and equipment requirements for extravehicular activity (EVA)? | 2 | N | - | 2 | - 8 | | _ <u>×</u> | _× | × | | | × | ···· | | N | N | | <u>,</u> | o, | 12 | | |
| | N N | က | | | How do circadian rhythm cycles and sleep influence 1111 performance and interact with the space environment to affect ability to accomplish mission | L 0 | 2 | N | | | <u>e</u> | _× | <u>×</u> | <u>×</u> | × | | × | | | | | | 4 | | | | · · · · · · · · · · · · · · · · · · · |
| | - R | ო | 4 | | pharmacology, lighting, etc.) can be developed to improve performance and productivity? What are the best psychophysiological correlates of effective performance variation in the space | 2 | N | N N | ع د | | | × | × | × | × | | × | | | | | | 4, | 'n, | 6, 7, | 80 | |
| | • | | 4 | | | | | | | | <u></u> | | · | | | | | | - | | _ | | | | | | |
| - | | <u> </u> | • | | motivation and the ability to cope effectively with environmental stress? | CI | ر در | <u>ო</u> | <u>N</u> | | ო | × | | × | | | × | | | α | | | 4 | | | | |
| | | | | | Of the various countermeasures available to combat adverse cardiovascular effects on longand short-duration missions, which are most | N | - 22 | <u>e</u> 9 | | 7 | <u></u> | × | × | × | × | × | × | | | | | + | , S | 4 | | | |
| | | | | | effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. | | | | | | | | | | | | | | | | | | | | | | |

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Table 5

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| | What are the specific mechanisms underlying the | | (force, internal frequency, and time interval)? Is there a threshold? What are the adaptations and deteriorations associated with prolonged exposure to unusual | atmospheric environments, including the impact of microgravity, and how can countermeasures be utilized against these deteriorations? What is the time course and extent of muscle atrophy during either prolonged spaceflight or | unloading? How is muscle metabolism regulated during normal activity and exercise, after acute and chronic unloaded states, and during recovery from | unloading? What are the effects of altered levels of hormones and their receptors in regulating the physiology of unloaded muscle? | What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and | function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuscluar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| ĺ | rit | What is the most effective way to restore red mass during simulated and actual microgravity Should red cell mass be restored during space flight? Are these acute or chronic changes and they of sufficient magnitude or duration to pose unacceptable medical risk and warrant the development of countermeasures (prophylactic therapeutic)? Formulate mathematical and computer models of tissue adaptation and cellutransient response to altered load histories? | Is the basal metabolic rate and metabolic efficiency altered during extended space flight? Are there changes in energy metabolism and storage in space, especially in substrate utilization? | What are the mechanisms underlying the negative nitrogen balance and changes in lean body mass incurred during space flight? What are the possible interventions, including dietary alterations in proteins and amino acids? | Do the effects of space flight require added supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? | What is the time course and nature of body composition change due to space flight? Do changes in body composition (age and gender) have an effect on crew health and performance? |
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| | 35 Critical Question | Are there appropriate animal and/or computer models for studying each functional element of cardiovascular adjustments to microgravity? | Are there changes in cardiac performance and contractile efficiency during long term exposure microgravity? | Is pulmonary function altered in long-duration space flight at rest, exercise, or in a disease state? | What are the physiological similarities and differences of ground- based models of muscle atrophy and fiber transformation and | weightlessness-induced muscle atrophy and fibe transformation? How valid are ground-based models for studying the characteristics of space-flight-induced muscle changes? What are the molecular signals and mechanisms that are responsible for the control of muscle hypertrophy and atrophy, and what are the specific stimuli that are generated by exercise disuse to signal increased or decreased protein accumulation in muscle cells? | What is the molecular interrelationship between catabolic and synthetic rates of protein metabolism in unloaded muscles? | What is the molecular basis for the effects of unloading on the susceptibility of muscle to injury or damage upon resuming normal weight-bearing states? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | ო • | | 4 | | What are the similarities and differences of ground-based models and spaceflight-induced bone and connective tissue loss with respect to biomechanical, histomorphometric, biochemical, and hormonal changes? | 505 | თ | 8 | - | - | - | ဇ | × | × | × | | × | | | N | _ | - | - | 3, 7 | | |
| | * 0 | ო | 4 | | What are histomorphological and architectural changes that occur in bone and connective tissue because of space-flight? | 5c7 3 | 8 | N | α | _ | ļ . | m | × | × | <u>×</u> × | | × | | | N | - | - | _ | 3, 7 | 7, 8 | |
| | | | 4 | | Which endocrine-receptor perturbations modulate tissue responsiveness to mechanical stresses? | 5d4 | <u>~</u> | N | _ | | - | m | × | × | × | <u> </u> | × | | | | _ | | - | 4 | | |
| | * N | | 4 | | Which specific models predict bone and connective tissue structural transients during altered load environments? | 5d5 3 | 7 | 0 | - | | _ | ო | × | × | × | × | × | | | _ | - | - | _ | | | |
| | α . | | 4 | | How do changes in mechanical forces and tissue stress (e.g., shear, stress) and/or electrical forces (piezoelectric and tissue streaming potentials) result in mechanisms that are associated with translational alterations in connective tissue structural proteins? | 6ps | 0 | N | 0 | - | - | e e | × | · · | × | <u> </u> | | | | α | - | - | - | <u>က်</u> | 8, | |
| | , | | 4 | | Is cytokine production and response to cytokine by osteoblasts and osteoclasts affected by exposure to microgravity? | 5d10 3 | ۰ ہ | N | N | | _ | ო | × | × | × | × | × | | | N | - | | _ | 7, 1 | 0 | |
| | · 0 | | 4 | | Are precursor cells of osteoblasts and osteoclasts affected by microgravity? | 5d11 3 | 0 | _ | 7 | _ | - | ო | × | × | × | <u>×</u> | × | | | _ | _ | - | | <u>, </u> | 0 | |
| | * | | 4 | | Do precursor bone cells respond to maturation stimuli in a microgravity environment as they do on earth? | 5d12 3 | 2 | - | N | _ | _ | ო | × | × | × | <u>×</u> | × | | | _ | | - | - | | 0 | |
| | . 2 | | 4 | | Do osteoblast require gravity to function normally? If developed in microgravity will they function normally? | 5d13 | 2 | - | N | _ | - | ဇ | × | × | × | × | × | | | _ | - | | | 7, 1 | 10 | |

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | 5 Critical Question | Are there changes in the processing of signals from the semicircular canals or otolith organs the occur with adaptation? Do these changes take place within the vestibular nuclei, cerebellar structures or other related brainstem and cortic structures? What is the time course of such changes and do they correlate with space motion sinkness? | What are the neural (morphophysiological) and neuroendocrine bases for motion sickness? What changes in neurotransmitters, neuroendocrine, or neurohumoral release can be correlated with space motion sickness? | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and output pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | What psychophysical correlates can best be used to 6c2a describe spatial orientation? | Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional environment? How do these |
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Critical Questions That Would Utilize Space Station Freedom (SSF)
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | | | | | gravito-inertial frame of reference? What are the | 9 | | | | | | | | | | _ | | | | | | | | | | | | | |
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| | * ~ | | | | What is the distribution of receptors for anti-motion sickness druos in central vestibular | 686 | 4 | n | . ັ | <u> </u> | | N | <u> </u> | <u> </u> | <u><</u> | < | < | <u> </u> | | | - | _ | _ | _ | oʻ ŧ | | | | |
| | | | | | pathways? | | | | | | | | | | | | | | | | | | | | | | | | |
| | * | 4 | | | What is the most appropriate three-dimensional | 6b1b | 4 | ო | ~ | 1 | _ | 8 | × | × | × | | × | × | | | _ | - | _ | - | ထ ယ | , 0 | | | |
| | | | | | model of the angular and linear VOR and of central | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | vestibular processing that will account for alterations in eve movements in microgravity? | | | | | | | | | | | | | | | | | | | | | | | | |
| | * | 4 | | | What models of sensory-motor transformation ca | can 6b7 | 4 | 2 | | | | 2 | × | × | × | × | × | × | | | - | - | - | - | э, 8, | , 10 | | | |
| | | - | | | be used to predict motor behavior best in altered | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | gravitational states? | | | | | | | | | | - | | | | | | | | | | | | | | |
| | 2 * 3 | | | | How are the following cell functions influenced by | y 811b3 | 4 | _ | _ | - | N | က | × | × | × | × | × | × | | | _ | _ | _ | - | _ | | | | |
| | | | • | | gravity and/or affected by microgravity: the | | | | | _ | | | | | | | | | | | | | | | | | | | |
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| | | | | | transduction, including signal-membrane | | | | | | | | | | | | _ | | | | | | | | | | | | |
| | | | | | interactions, membrane-effector interactions, and | | | | | | | _ | | | | _ | | | | | | | | | | | | | |
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| | | | | | intracellular transport; secretion; alternate | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | pathway regulation; and cell-to-cell | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | communication? The importance of selecting cell | sells | | | | | | | | - | | | | | | | | | | | | | | | _ |
| | | | | | and cell lines that can provide interpretable results | ılts | | | | | | | _ | | _ | | | | | | | | | | | | | | |
| | | | | | bearing on precise questions cannot be | | _ | | | _ | | | | | _ | | | | | | | | | | | | | | |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| _ | | | ~ | 8VI6 | 2b1 1 3 | | 214 | 3a3 |
| Question Quest# Cr | 4 | 4 | altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | | ine 2b1 1 | changes on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | What are the effects of microgravity on renal 214 1 1 function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? |
| Question Quest# Cr | 8Vb7 4 | 8VI2 4 | altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | 8VI6 | What are the effects of space-induced endocrine 2b1 | | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | ne cardiovascular responses to lar activity (EVA) at various levels of 1., microgravity, planetary surface? What factors influence the magnitude, and sequence of these |
| Question Quest# Cr | What role do endocrine and neural systems play in 8Vb7 4 controlling/modifying adaptation to gravity? | What are the systemic, local, cellular, and 8VI2 4 subcellular mechanisms involved in adaptation to | altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | What are the biochemical pathways responsible for 8VI6 synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to altered gravity? | What are the effects of space-induced endocrine 2b1 | | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? |
| Question Quest# Cr | What role do endocrine and neural systems play in 8Vb7 4 controlling/modifying adaptation to gravity? | What are the systemic, local, cellular, and 8VI2 4 subcellular mechanisms involved in adaptation to | altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | What are the biochemical pathways responsible for 8VI6 synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to altered gravity? | 3 * 4 What are the effects of space-induced endocrine 2b1 1 | | What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these responses? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| Quest# | 3a12 | 363 | 4c2 | 403 | 4c9 | 5a9 | 5c4 | 7g6 |
| C2 C3 C4 C5 Critical Question | Following long-term space flight, are there delayed or persistent consequences, either beneficial or harmful? As a corollary, are there appropriate rehabilitative measures that should be applied both in the near-term (hours to days) and long-term (months to years) after flight? | Which pulmonary life support procedures should be used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? | What procedures and approaches prevent decompression sickness or minimize crew risk? | Treatment of medical problems of spacecraft inner temperature, and adverse effects of the gaseous environment? | What are the risks for bubble formation and clinical decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? | Does the atrophy from unloading make muscle, tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | What potential risks does bone loss present to the tedevelopment of bone fractures, hypercalcemia, metastatic calcification, and renal stone formation? | How are risks associated with acute exposure to |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| Quest# | 2014 | 2e15 | 2g1 | 3a6 | 389 | 3a13 | 4b3 | 5a10 |
| Question | What is the nature of space flight-induced changes 2e14 in effect of vasoactive drugs? | What is the nature of space flight-induced effect of 2e15 pharmocokinetics of drugs? | What are the effects of space flight and/or EVA on 2g1 thermoregulation processes and heat exchange? | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | | Since microgravity alters blood pressures and flows to some tissues, what are the structural and functional consequences in these various tissues and organ systems with long-duration flights? | What is the effect of long-duration space flights on 4b3 the human immune system? (Reg. Physiol see p. 6) | |
| Question | What is the nature of space flight-induced changes 2e1 in effect of vasoactive drugs? | ct of | What are the effects of space flight and/or EVA on thermoregulation processes and heat exchange? | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | Does the extent of adaptation affect postflight orthostatic tolerance? | Since microgravity alters blood pressures and flows to some tissues, what are the structural and functional consequences in these various tissues and organ systems with long-duration flights? | What is the effect of long-duration space flights on the human immune system? (Reg. Physiol see p. 6) | How completely and how well does injured muscle 5a10 repair in microgravity? |
| Question | ht-induced changes 2e1 | ct of | | | | and | What is the effect of long-duration space flights on the human immune system? (Reg. Physiol see p. 6) | well does injured muscle 5a10 |
| Question | What is the nature of space flight-induced changes 2e1 in effect of vasoactive drugs? | What is the nature of space flight-induced effect of pharmocokinetics of drugs? | What are the effects of space flight and/or EVA on thermoregulation processes and heat exchange? | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | Does the extent of adaptation affect postflight orthostatic tolerance? | Since microgravity alters blood pressures and flows to some tissues, what are the structural and functional consequences in these various tissues and organ systems with long-duration flights? | ts on p. 6) | How completely and how well does injured muscle 5a10 repair in microgravity? |
| | What is the nature of space flight-induced changes 2e1 in effect of vasoactive drugs? | What is the nature of space flight-induced effect of pharmocokinetics of drugs? | What are the effects of space flight and/or EVA on thermoregulation processes and heat exchange? | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | Does the extent of adaptation affect postflight orthostatic tolerance? | Since microgravity alters blood pressures and flows to some tissues, what are the structural and functional consequences in these various tissues and organ systems with long-duration flights? | 3 * 4 What is the effect of long-duration space flights on the human immune system? (Reg. Physiol see p. 6) | 3 * How completely and how well does injured muscle 5a10 repair in microgravity? |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| | | | | | from ruptured follicles during ovulation? What is | | | | | | | | _ | | | | | | | | | | | | | | | | |
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| _ | | | | _ | reversed in the short- or long-term? | | | _ | | | | | | | | | | | | | | | | | | | | | _ |
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| | ო | * | | | How does gravity affect compensatory | 0//20 | _ | • | , | | | | | | | | | | _ | | | | | | | | | | |
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| | | | | | regenerative processes)? What is the interaction | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | with growth stages? What is gravity's effect on | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | wound healing? | | | | | | | _ | | | - | | | | | | | | | _ | | | | | |
| | ო | 4 | | | Are there in-vitro tests that reliably predict | 243 | | c | • | c | - | | | | | | _ | | | • | • | | | | | | | | |
| | | | | | decreases in immune function in space flight? | | | <u> </u> | | V | <u> </u> | , , | <u>`</u> | ` | ` | - | | | | _ | _ | _ | _ | တ | 0 | | | | |
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| | ო_ | 4 | _ | | How long do neutrophilia, lymphocytopenia, | 2d9 3 | 7 | 4 | 2 | 2 | _ | 2 | <u>~</u> | ^ | × | _ | | | _ | _= | _ | _ | - | 4 | | | | | |
| | | | | | monocytopenia, eosinopenia, and reduced | | | | | | | | | | | | | _ | | | _ | | | - | | | | | |
| _ | | | | | blastogenic responses persist after flight? | | _ | | | | | | _ | _ | | _ | | | | _ | | | | | | | | | |

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| Question Quest# Cr1 | 294 3 3 rugs | 2611 3 2 | 211 | from 2f6 3 | 352 3 | 8Vb3 | 217 3 |
| Critical Question | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space | pace flight alter gastrointestinal function, g the absorption of essential nutrients and stioning of gut flora? What are the effects e flight on liver function? Are the effects | oversible? Ind magnitude of fluid 2f1 3 compartment volumes ypogravity and during | 2f6 3 | rogravity, does the 3b2 3 sause deeper penetration lung? In the spacecraft aerosol concentrations, bacterial | health hazard? What is the role of gravity on thirst and feeding 8Vb3 3 behaviors (appetite, taste preference, and thresholds)? | mechanisms inducing the acute loss of 217 3 ctrolytes in microgravity? |
| Critical Question | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space | Does space flight alter gastrointestinal function, 2e11 3 2 including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects | progressive? Are they reversible? What are the time course and magnitude of fluid 2f1 3 shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during | What are the time course and magnitude of the 2f6 3 diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | 352 3 | 8Vb3 | What are the mechanisms inducing the acute loss of 217 3 fluid and electrolytes in microgravity? |
| Critical Question | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space | Does space flight alter gastrointestinal function, 2e11 3 2 including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects | progressive? Are they reversible? What are the time course and magnitude of fluid 2f1 3 shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during | What are the time course and magnitude of the 2f6 3 diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations, particle size profiles, and bacterial contaminations? Do these factors constitute a | health hazard? What is the role of gravity on thirst and feeding 8Vb3 3 behaviors (appetite, taste preference, and thresholds)? | 4 • What are the mechanisms inducing the acute loss of 217 3 fluid and electrolytes in microgravity? |
| Critical Question | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space | Does space flight alter gastrointestinal function, 2e11 3 2 including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects | 211 | What are the time course and magnitude of the 2f6 3 diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | 352 3 | health hazard? What is the role of gravity on thirst and feeding 8Vb3 3 behaviors (appetite, taste preference, and thresholds)? | 3 4 * What are the mechanisms inducing the acute loss of 217 3 fluid and electrolytes in microgravity? |
| Question Quest# Cr1 | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space | Does space flight alter gastrointestinal function, 2e11 3 2 including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects | progressive? Are they reversible? What are the time course and magnitude of fluid 2f1 3 shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during | What are the time course and magnitude of the 2f6 3 diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations, particle size profiles, and bacterial contaminations? Do these factors constitute a | health hazard? What is the role of gravity on thirst and feeding 8Vb3 3 behaviors (appetite, taste preference, and thresholds)? | 4 • What are the mechanisms inducing the acute loss of 217 3 fluid and electrolytes in microgravity? |

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| 1 | | For the well documented changes in calcium metabolism associated with space flight, what are the direct and indirect consequences for electrical, mechanical, and vascular events in the heart? | Does space flight affect pulmonary aging or diserprocesses commonly found in adults in a 1-genvironment? How is subclinical pulmonary pathology (e.g., incipient bronchospasm, early emphysema) affected by space flight? Do these same questions apply to healing processes in the lung? | In terms of the fluxes of matter and energy that maintain disequilibrium conditions, what universal metrics can be developed for assessing the potential of different microenvironments to support the origin and evolution of life? | What fluxes of intact organic compounds could been supplied to the Earth's atmosphere and surface waters by accretion of cometary or carbonaceous chondritic material? | What photochemical processes occurred in the atmosphere, at the interfaces of the atmospher with oceans and land, and in surface waters? | xter Fern Jour | What evidence is compounds of a including Earth? |
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| Ŀ | ა | The The | Does proce envirc patho emph same lung? | ma ma mel pot | Surf Sart | with With | To what extent has chemical evolution of the biogenic elements and compounds occurred on planets other than Earth, and why did it take different courses? | What evidence is there for the presence of biogenic compounds of abiotic origin in planetary materials, including Earth? |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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Table

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

Table

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| | If multicellular systems are necessary for gravity sensing, how is this effected? What cellular structures and processes that extend across several cells might be involved? What aspects of cell-cell communication are affected? Would the requirements for cellular interaction/assembly increase sensitivity to indirect or environmentalli | mediated effects (e.g., reduction of cell-cell and cell- surface contact by dispersion of cells in microgravity)? What are the mechanisms involved in the transduction of the stimulus of altered | gravitational force to a cellular response; by what pathways is the perception of altered gra relayed intracellularly and/or extracellularly? How does gravity affect organogenesis and the development of anatomical structures? — Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular, | musculoskeletal) of young and adult animals similarly sensitive to this stimulus in ontogeny? What are the optimal conditions for synchronizing the circadian rhythms of mission control personn to the mission schedules? How is performance o mission personnel affected by their various wor | rest schedules? What are the long-term effects of the space environment on the interaction between the circadian system and ultradian and infradian rhythms, especially reproductive systems? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | | What are the hypothalamic-pituitary-adrenal aropiold system responses to normal space-flight events (e.g. EVA, countermeasures) as well as reference "standardized" physical, emotional, environmental stimuli? | f sp and | How does space flight affect the pharmacodynamics of hormone action, the permeability of the blood-brain barrier, and the action and metabolism of hormones? | How do altered biological rhythms associated will long-term space flight affect hormone secretion and function and vice versa? | ss of | What is the relationship between altered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | What are the major factors and associated mechanisms that contribute to the "anemia of space flight"? | ₩ . | impairment of the red cell mass result from an impairment of the red blood cell proliferation process or to differential margination, | rencoloerication sequestration, cell death, or other mechanisms? |
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| | riti | What are the hypothals opioid system response events (e.g. EVA, count reference "standardizec environmental stimuli? | What are the acu flight on endocrin responsiveness? | ow o | ow c ng-t | What a change flight? | hat mat rels | What are the n mechanisms th space flight"? | What controls the alt production or survival? | pain pain oces | other mechanisms? |
| | C2 C3 C4 C5 Critical | What are the hypothalamic-pituitary-adrenal and opioid system responses to normal space-flight events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, are environmental stimuli? | What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | 5 • How does space flight affect the pharmacodynamics of hormone a permeability of the blood-brain taction and metabolism of hormor | 5 * How do altered biological rhythms associated with long-term space flight affect hormone secretion and function and vice versa? | 5 * What are the time courses and magnitudes of changes in the erythropoletic system during stilight? | * | 5 What are the major factors and associated mechanisms that contribute to the "anemia space flight"? | اقرا | Εğ | <u>₹</u> |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Group w/ other Disc 17 18 11 12 13 14 15 16 × × 10 × × × o × × × × œ × × 9 က N Quest# Cr11 4 208 2d1 2c7 phlebotomy, and can this recovery be accelerated? Is the "anemia of spaceflight" related to a direct space crews in a manner that would expose them immunity, or immune surveillance capabilities of subjects who donate blood or otherwise undergo Are periods of recovery from "anemia of space to unacceptable medical risk while on a mission, space-flight-induced stressors on bone marrow structure, function, or cellular interaction? cell-mediated immune functions, nonspecific upon return to Earth, or as a consequence of flight" physiologically analogous to those in Does space flight affect the humoral or effect of microgravity or other repeated mission exposure? Question C3 C4 C5 Critical ۍ د 5 ۍ * N ਨ

1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Paralle//Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centifuge 11=Free Flyer 12=Lunar Base 13=Roboic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| Critical Question | What are the time course and magnitude of space-flight-induced changes in the surface phenotypes (subpopulations), circulation patterns, or functional capacities of the cells of the immune system, including mucosal, humoral, cell-mediated and immune surveillance systems? — What factors cause or otherwise influence the consistently demonstrated post-flight reduction in blastogenic responsiveness to nonspecific mitogens (PHA, Con A, LPS)? — What are the dynamics of the leukocyte count during space flight with respect to: — Induction of neutrophilla, lymphopenia, monocytopenis or eosinopenia — •numbers and functional capacity of natural killer (NK) cells | the circulation/sequestration of immunologically active cells? What are the effects of space flight on the functional capacities of the effector/accessory cells of specific or nonspecific immunity | (monocytes, neutrophils, macrophages, lymphocytes, and NK cells)? Do any of the changes in the immune system predispose crewmembers either during or after flight to infectious diseases, allergies, or delays recovery from disease or wound healing? | What are the energy requirements of EVA? are the effects of deconditioning, EVA, and |
| | What are the time course and magnitude of space-flight-induced changes in the surface phenotypes (subpopulations), circulation p or functional capacities of the cells of the isystem, including mucosal, humoral, cell-nand immune surveillance systems? — What factors cause or otherwise influen consistently demonstrated post-flight reduciblastogenic responsiveness to nonspecific re(PHA, Con A, LPS)? — What are the dynamics of the leukocyte during space flight with respect to: — Induction of neutrophilia, lymphopenia, monocytopenis or eosinopenia — •numbers and functional capacity of na killer (NK) cells — other changes in the WBC differential or | the circulation/sequestration of immunologactive cells? What are the effects of space flight on the functional capacities of the effector/accescells of specific or nonspecific immunity | (monocytes, neutrophils, macrophages, lymphocytes, and NK cells)? 5 *Do any of the changes in the immune system predispose crewmembers either during or a flight to infectious diseases, allergies, or de recovery from disease or wound healing? | 5 * What are the energy requirements of EVA? What are the effects of deconditioning, EVA, and |
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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality S Table

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| | Question Quest# Cr | 5 * Are there valid ground models and analogs for the 2e7 study of the effects of space flight on nutrition? | 209 | crew health and performance in space flight? What are the behavioral and performance responses of | individuals to particular food constituents during space flight? Are there changes in dietary | gies" 2e10 | 2e12 | Ze13 | 5 * What are the relationships of fluid and electrolyte 2f11 responses to space flight on sensory thresholds and space motion sickness? | 5 To what extent does the qastrointestinal system 2f13 modify electrolyte and fluid balance control during space flight? | 5 * What are the compounded effects of microgravity 2g2 and EVA on thermoregulatory processes and heat exchange? | 5 * How does the regulation of body temperature 2g5 change during space flight? How do these changes affect the response to thermal load? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | Question Quest# C | 296 | 2g7 | 999 | * How do neural mechanisms regulate homeostatic 6b8 processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | What perceptual and performance changes are 6c6 produced by drugs used in treatment of motion sickness? | *What are the mechanisms that underlie gravity 8la1 perception? | 8la2 | 81a3 | 8la5 ogravity? | 8167 | 8lc3 | secretion? What are the mechanisms by which transport 81c6 systems are polarized in plants grown in space? |
| | Question Quest# C | 2g6 d | * How does space flight affect central and/or 2g7 peripheral thermoregulatory mechanisms? | Does a change in otolithic and proprioceptive 6b6 activity function play a role in regulating calcium or antigravity muscle growth and function during development and aging and exposure to attered gravitational states? | 6b8 | 909 | 8la1 | ents in gravity 81a2 | 81a3 | 8la5 | 8167 | int on 81c3 | 81c6 |
| | C3 C4 C5 Critical Question Quest# C | 5 How are changes in body temperature or its 2g6 regulation correlated with metabolic rate and energy expenditure? | * How does space flight affect central and/or 2g7 peripheral thermoregulatory mechanisms? | 5 * Does a change in otolithic and proprioceptive 6b6 activity function play a role in regulating calcium or antigravity muscle growth and function during development and aging and exposure to attered gravitational states? | 5 * How do neural mechanisms regulate homeostatic 6b8 processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses? | What perceptual and performance changes are 6c6 produced by drugs used in treatment of motion sickness? | *What are the mechanisms that underlie gravity 8la1 perception? | 8la2 | 81a3 | 8la5 ogravity? | 8167 | 8lc3 | secretion? What are the mechanisms by which transport 81c6 systems are polarized in plants grown in space? |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | | w can gravity be us rturbing cell structu other effectors? | ich developmental dependent on the | iich organ systems wity field and ve | nsidering developi ases, beginning w | gressing through | resent different species and phyla? How will gravitational fields particulated | rogravity, disturb | stural control requ | vity as do their | ose animals which both environment study. | what stage can a adian rhythms, I bect to different | w do specific orgelopmentally to nonstrated by the sin transgenic etic makeups? |
| | | How can gravity be used as a research tool in perturbing cell structure/function in the absence of other effectors? | Which developmental mechanisms have evolved to be dependent on the 1-g gravity field and vector? | Which organ systems are gravity field and vector? | Considering development as a series of stages or phases, beginning with pattern specification, and | progressing through differentiation, how will gravity affect selected phases in animals that | represent different species and phyla? How will gravitational fields | microgravity, disturb the precise coordination | postural control required in mating? — Will acutatic animals perceive and recoond t | gravity as do their terrestrial counterparts? | I hose animals which pursue different life stages in both environments may be particularly valuable for study. | At what stage can we observe perturbations circadian rhythms, both temporally and with respect to differentiation state? | How do specific organs and tissues respond developmentally to altered gravity, as demonstrated by the expression of selected ta genes in transgenic mice with pre-determined genetic makeups? |
| | | 5 * How can gravity be used as a research tool in perturbing cell structure/function in the abser of other effectors? | 5 * Which developmental mechanisms have evolved to be dependent on the 1-g gravity field and vector? | 5 * Which organ systems are dependent on the 1-g gravity field and vector? | 5 * Considering development as a series of stages phases, beginning with pattern specification, a | progressing through gravity affect select | represent different s | microgravity, disturb | postural control requested will actuate animals. | gravity as do their | I hose animals which in both environment for study. | 5 * At what stage can we observe perturbations o circadian rhythms, both temporally and with respect to differentiation state? | 6 + How do specific organs and tissues respond developmentally to altered gravity, as demonstrated by the expression of selected tagenes in transgenic mice with pre-determined genetic makeups? |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

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| Question Quest# Cr11 | in 81110 | What are the effects of gravity, in concert BIII11 particularly with life in closed ecosystems, on sexual maturation? | * How does gravity produce responses in cultured cells that mimic those seen in chronologically aged cells, those isolated from accelerated aging syndromes, and senescent cells in vitro? — Which de-limiters of lifespan have relevance to gravitational effects? | * Is gravity a continuum in terms of 8IVa1 stimuluş/response? | *What is the role of gravity in the evolution of 81Va2 animal gravity sensors? | 8IVa3 | 81Va4 Iravity | 81Vb2 |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| | Question | <u>+</u> | Is there a fundamental principle of gravity sensor information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | Is there a relationship between otoconial or statolith load and the acceleratory environment, and/or between this load and the neural substrate? | What are the principles of organization, and the inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are placed in altered-g environments? Are there restrictive mechanisms in some species that prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased oravity?) | Will animals bred in microgravity or hypergravity be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are tuned to a gravitational extreme? Is it Earth's environmental position, off an extreme, that permits adaptive responses? | Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? | * Does development of a gravity receptor in an altered-g environment affect the ability of the |
| | Question | <u>+</u> | Is there a fundamental principle of gravity sensor information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | Is there a relationship between otoconial or statolith load and the acceleratory environment, and/or between this load and the neural substrate? | What are the principles of organization, and the inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are placed in altered-g environments? Are there restrictive mechanisms in some species that prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased oravity?) | Will animals bred in microgravity or hypergravity be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are tuned to a gravitational extreme? Is it Earth's environmental position, off an extreme, that permits adaptive responses? | Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? | Does development of a gravity receptor in an altered-g environment affect the ability of the |
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Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality

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| , | ပ | the 8Va3 | 8Vb6 sms, | 8Vb8 | 8Vb11 | how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 | 8VI12 rred lently? |
| | ပ | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | ပ | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | ပ | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | ပ | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | ပ | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | Quest# | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
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| | ပ | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | Question Quest# C | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | Question Quest# C | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | Question Quest# C | the 8Va3 | 8Vb6 chanisms, | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | Question Quest# C | the 8Va3 | 8Vb6 chanisms, | * How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 | *Is gravity necessary for sex behavior? If so, how 8Vb12 does gravity affect it and what are the mechanisms? | 8Vb13 | 8Vb14 what | * Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? | * Is the relationship between muscle and bone RVI12 necessary for an integrated response to altered gravity or do the systems respond independently? |
| | Question Quest# C | ween the 8Va3 | 8Vb6 sms, | 8Vb8 | d 8Vb11 | If so, how 8Vb12 | 8Vb13 | 8Vb14 what | 8VI3 ological /? | 8VI12 rred lently? |
| | Question Quest# C | the 8Va3 | 8Vb6 chanisms, | * How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 | *Is gravity necessary for sex behavior? If so, how 8Vb12 does gravity affect it and what are the mechanisms? | 8Vb13 | 8Vb14 what | * Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? | * Is the relationship between muscle and bone RVI12 necessary for an integrated response to altered gravity or do the systems respond independently? |
| | Question Quest# C | the 8Va3 | 8Vb6 chanisms, | * How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 | *Is gravity necessary for sex behavior? If so, how 8Vb12 does gravity affect it and what are the mechanisms? | 8Vb13 | 8Vb14 what | 5 * Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? | * Is the relationship between muscle and bone RVI12 necessary for an integrated response to altered gravity or do the systems respond independently? |
| | Quest# | the 8Va3 | 8Vb6 chanisms, | * How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 | *Is gravity necessary for sex behavior? If so, how 8Vb12 does gravity affect it and what are the mechanisms? | 8Vb13 | 8Vb14 what | * Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? | * Is the relationship between muscle and bone RVI12 necessary for an integrated response to altered gravity or do the systems respond independently? |

Critical Questions That Would Utilize Space Station Freedom (SSF) Listed by Category and Criticality Table 5

| ٥ | C2 C3 C4 C5 Critical Question | Quest# | Cr1 | 1 | 3 | 4 | 2 | 9 | 7 | 00 | 6 | 0 | - | 2 | 9 | 4 | 5 16 | 6 1 7 | 18 | | /× d | Group w/ other | ا ۵ | Disc |
|---------------------------|---|-------------|----------|---|---|---|---|---|---|----|---|---|----|--------|-------|----------|----------|-------|----------|----------|------|----------------|-----|------|
| h mech | 5 • Which mechanisms of adaptation of the | 8VI16 | 4 | _ | | _ | | | × | × | × | × | × | | | _ | N | | - | 7 | | | | |
| culoskel | musculoskeletal systems of rats, monkeys, and humans to altered gravity are similar and which | | | | | | - | | | | | | | | | | | | | , | | | | |
| manism | mechanisms are different? | T (| | | | | | | × | × | × | | | × | | N | N | | _ | | | | | |
| t IS th ution solar | what is the degree of molecular complexity and evolution in circumstellar, interstellar, and protosolar environments? | _ g _ | <u> </u> | | | | | | | (| | | | | | | | | | | | | | |
| t is t | 5 * What is the composition, structure, and | 11a2 | 4 | | | | | | × | | × | | ^_ | × × | | _ | N | | - | | | | | |
| rela stelk | inter-relationships between circumstellar, interstellar and interplanetary dust? | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | 5 * What is the efficacy of chemical and physical | 11a3 | 4 | | | | | | × | | × | | | × × | | <u> </u> | CI_ | | | | | | | |
| esse | processes in the ptotosolar nebula for altering | | | | | | | | | | | | _ | | | - | | | | | | | | |
| exist | pre-existing materials and producing new | | | | | | | | | | | | | | | | | _ | | | | | | |
| ō | compounds and phases containing the biogenic | | | | | | | | | | | | | | | _ | | | | | | | | |
| elements? | 8.5 | | | | _ | _ | | | | | | | | | | | | • | | | | | | |
| ha | 5 * How has the formation and evolution of primitive | 11a4 | 4 | | | | | | × | | × | | | × | | | α_ | - | <u>-</u> | | | | | |
| θS | bodies modified the distribution, structure, and | | | | | | | | | | | | | | | | | | | | | | | _ |
| posi | composition of pre-existing compounds and phases | | | | | | | | | | | | | | | | _ | | | | | | | _ |
| pro | and provided mechanisms for production of new | | | - | | | | | | | | | | | | | | | | | | | | |
| species? | ċ | | | | | | | | | | | | | | | | | | | | | | | |
| ıt İs | 5 * What is the distribution, structure and composition | 11a5 | 4 | | _ | | | | × | | × | | | × | × | | 2 | _ | _ | | | | | |
| resc | of presolar and nebula products in existing | | | | | | | | | | | | | _ | | | | | | | | | | |
| itive | primitive materials in the solar system? | | | | | | | | | | | | | | | | | | | | | | | |
| er × | 5 * Under what conditions could methane or carbon | 11511 | 4 | | | _ | | | × | | × | | | × | × | | 2 | _ | | | | | | |
| oxid | e, rather than carbon dioxide, have been | | | | | _ | | | | | | | | | | | | | | | | | | |
| olied | supplied as the dominant carbon source at Earth's | | | | | | _ | | | | | | | | | | | | | | | | | |
| surface? | 9.5 | | | | | _ | | | | | | | | ٦ | ┪ | ┫ | \dashv | ㅓ | \dashv | \dashv | | | | ٦ |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Hyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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TABLE 6

CRITICAL QUESTIONS THAT WOULD UTILIZE THE SSF CENTRIFUGE FACILITY LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- 1 = Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- 3 = Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- 4 = Science Specifically enabled by Moon and/or Mars Missions.
- Basic Research Not Directly Applicable to Moon and/or Mars Missions.
 - Indicates primary category of application.

CRITICALITY

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3; Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.
- *Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| 1. | Science Readiness Levels |
|----|--|
| ١. | Only folklore of practitioners and anecdotal data available |
| | 2. Basic scientific concept formulated |
| | Ground models developed, flight validation required |
| | 4. Flight validation performed |
| | 5. Countermeasures identified |
| | 6. Countermeasures tested |
| | 7. Operational requirements established |
| 2 | Technology Readiness Levels |
| 2 | |
| | |
| | 2. Technology and conceptual solution available |
| | 3. Component and/or breadboard validation in laboratory |
| | environment exist |
| | 4. Flight validation performed |
| | 5. Systems/subsystem prototype demonstration in a relevant |
| | ground or space environment completed |
| | 6. System prototype demonstrated in a space environment |
| | Actual system completed and flight qualified through test an |
| | Demonstration |
| | Actual system "flight proven" through successful mission operations |
| 3 | Schedule (information required by) |
| 3. | |
| | 1. = Near term < 5 years |
| | 2 = Mid term 6-10 years 3 = Far term > 10 years |
| | |
| 4. | Effort Required |
| | 1. = Substantial |
| | 2 = Moderate |
| _ | 3 = Low |
| 5. | Defined Sequence (Clearly defined sequential path for scientific investigation exists) |

Parallel/Alternative Path (are parallel or alternative pathways

Ground-based research required

Program research

Spacelab would be used for research

Space Station Freedom would be used

Spacelab needed for Extended Duration Orbiter

Yes

No

No

appropriate)

Ground-based

Spacelab

EDO

SSF

7.

10. Centrifuge SSF Centrifuge Facility would be used Free Flyer 11. Free flyer biosatellite Lunar Base 12 Lunar base would be used 13 Robotic Explore Robotic explorer would be used Other Requirements Requirement for flight resources other then those identified in 8-10 Flight Validation Required Flight validation required Not required Facilities Sufficient Current ground facilities (NASA Centers, Universities and provide industry) are sufficient Current ground facilities insufficient Community Sufficient There is a sufficient scientific community already committed or recruitable Scientific community is insufficient **Attract New Community** Activity will attract new scientists Activity will not attract new scientists Group with other disciplines (can this activity be grouped with others from different life science disciplines?) No, cannot be prouped Do not know at this time 3 Behavior, Performance and Human Factors Regulatory Physiology 4 5 Cardiopulmonan Environmental hea 6. 7. **Musculoskeletal** Neuroscience 8 Radiation Health **Cell and Developmental Biology** 10. Plant Biology 11. Life Support

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table 6

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| O | 4a1 2 | | 8la4 2 | 8la6 | 8lb1 2 | 81b2 2 | in 81b3 2 | 81b4 | 2 | 8lb6 2 |
| O | 4a1 2 | | 8la4 2 | 8la6 | 8lb1 2 | 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| O | 4a1 2 | | 8la4 2 | 8la6 | 8lb1 2 | 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| O | 4a1 2 | 462 | 8la4 2 | 8la6 | 8lb1 2 | 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| O | 4a1 2 | 462 | 8la4 2 | 8la6 | 8lb1 2 | vior during cell 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| O | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| O | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| O | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Quest# C | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Quest# C | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | in 81b3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Quest# C | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Question Quest# C | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Question Quest# C | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Question Quest# C | 4a1 2 | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Question Quest# C | 4a1 | | N | 81a6 | N | 0 | 81b3 2 | | 2 | lants or single 8lb6 2 |
| Question Quest# C | 4a1 2 | What is the effect of space flight on all 4b2 microorganisms? | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Question Quest# C | What impact do space flight-induced biological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | 462 | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| C3 C4 C5 Critical Question Quest# C | 4a1 2 | What is the effect of space flight on all 4b2 microorganisms? | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |
| Question Quest# C | What impact do space flight-induced biological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | What is the effect of space flight on all 4b2 microorganisms? | 8la4 2 | 8la6 | duce through more 8lb1 2 | vior during cell 81b2 2 | or organ differentiation affected in 8lb3 2 | 8 lb 4 | 8155 2 | 8lb6 2 |

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table

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|--------------|-----|----------|---|---|---|---|--------|--------|--------------|--------------|--------------|--------------|----------|----------|---|---|----|----|----|----|----|----|------|--------------|--------------|---------|----------|------|
| ਹ | 8 | 8 | 3 | ৪ | C1 C2 C3 C4 C5 Critical | Question | Quest# | C | - | 2 | 3 4 | 2 + | 9 9 | 4 | 8 | 6 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 G | Group w | w/ other | Disc |
| - | | • | 4 | | Are there radiation microgray biological | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | 81b8 | 8 | - | 2 | - | _ | | × | × | × | × | × | × | × | | - | 8 | 8 | <u></u> | | | |
| - | · · | | | | Are anabolic an photosynthetic amicrogravity? | d catabolic pathways and the apparatus and pathway altered in | 8lc1 | 0 | α' | 2 | - | | | <u>×</u> | × | × | × | | | | | - | N | N N | - | 8 | | |
| - | | | | | What effi | What effect does microgravity have on the synthesis of storage and support polymers? | 81c2 | N | 2 | 2 | - | - | <u>£</u> | <u>~</u> | × | × | × | | | | | _ | N . | N | <u>-</u> | 8 | | |
| - | | | | | Are path in micro | Are pathways for plant nutrient absorption aftered in microgravity? | 8lc4 | N | - | - | - | _ | <u>¥</u> | × | × | × | × | | | | | - | 8 | N | 1 12 | Q | | |
| - | | | | | What are the ellong distance tr transpiration? | flects of the space environment on ansport of water and on | 81c5 | N | - | - | | | <u>£</u> | × | × | × | × | | | | | - | CI . | ~ | | | | |
| - | 47 | ω 4 | 4 | | How is the cells influ | How is the effect of gravity (and microgravity) on cells influenced by magnetic fields and radiation? | 81lc1 | , N | - | - | _ | - 24 | <u>e</u> | × | × | × | × | × | × | × | | _ | N | , , | <u>6</u> | | | |
| - | | <u> </u> | 4 | | Can crop extra-terr | | 9a1 | N N | m | 8 | - | | | × | × | × | × | × | × | | | - | 8 | - | <u>6</u> | 10, | = | |
| | • | | | | following studying | following constraints should be considered in studying this question: | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | - Closed en Recycling | Closed environments Recycling | | - | | | | | | | | | | | | | | | | | · | | | |
| | | | | | - Limite - Gravi | Limited space Gravity effects | | | • | | | | | | | | | | | | | | | | | | | |
| | | | | | - Phyto | Phytogenic volatile compounds and other trace | | | | - | | | | | | | | | | | | | | | | | | |
| | | | | | contaminants Radiation | ants ion | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | | | Adve — | Adventitious biota (microbial and other) | | | | | | | | | | | | | | | | | | _ | | | | |

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| Quest# | 9a3 | | | | 9639 | 9640 | 9e41 | 4 a5 | 7g5 |
| Question | What conditions are required to optimize the food generating and water recycling capacity of crop plants? The following factors represent the | minimum that should be considered in studying this question: Light quantity, quality, periodicity, as | composition and density — Root environment: substrate, nutrients, | volume, temperature, etc. — Aerial environment: gas composition and pressure, temperature, planting density, etc. | What is the productivity, transpiration, and dry matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | What is the morphology and reproductive capability of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for space bases? | What countermeasures can be utilized if productivity or reproduction is significantly decreased? | What are the potential biomarkers for assessing either exposure or response to chemicals? | What is the probability for genetic and developmental detriment incurred as a consequence of radiation exposure in space? |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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| * | <u>n</u> | | | What is the role of gravity in the regulation of circadian rhythms? — What are the effects of the absence of gravit on the generation, expression (period, phase, amplitude and/or waveform) and entrainment of circadian rhythms? — Is it at the synchronizing agent (zeitgeber)? — If not, is it necessary for the action of other synchronizing agents (light, exercise)? — What is the role of gravity in the ontogeny of circadian rhythms? — Is there a difference in the role of gravity across the phylogenetic scale? Single cells to complex organisms? — What is the gravity threshold for it actions in | at is the role of gravity in the regulation of sadian rhythms? What are the effects of the absence of gravity the generation, expression (period, phase, plitude and/or waveform) and entrainment of sadian rhythms? Is it at the synchronizing agent (zeitgeber)? If not, is it necessary for the action of other chronizing agents (light, exercise)? What is the role of gravity in the ontogeny of adian rhythms? Is there a difference in the role of gravity oss the phylogenetic scale? Single cells to the organisms? What is the gravity threshold for it actions in | 8Va1 | 6 | - | _ | Q | 2 | 3 | × | × | × | | | | - | N | | <u> </u> | 4 | | | |
| * | | 4 | | the regulation of circadian rhythms? Does this gravity threshold vary with the complexity of organism? What types and surface area of plants will be required to meet the production rate demands frevitalized air and what environmental condition of these plants. | the for | 9c30 | М | N N | <u>-</u> | α | N | - | × | × | <u>×</u> | | × | | | N | | _ | <u>က်</u> | | | |
| * - | <u> ෆ</u> | 4 | | What environmental conditions of space flight influence temperature regulation? | | 2g3 | 4 | <u>8</u> | 8 | N | 7 | က | | × | <u>×</u> | | | | | | - | | 4 | | | |
| 0 0 | <u>e</u> | 4 4 | <u> </u> | How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? What are specific countermeasures that impact effectively upon bone and connective tissue structure and function? | | 1a9 5c3 | | 2 2 | <u>ო ი</u> | - 2 | ო - | т т | ×× | × × × | ×× | | ×× | | - - | | | - - | φ | , 5, 6, | N | |

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| | | to the nato-sensory ation flights | d sleep influence space complish mission j., developed to tivity? | ical correlates n the space siological | lable to Is on long- re most be applied, but are not tion, | nderlying the ter flight? ures for this? | ardiovascular gravity levels e interval)? Is | of muscle ceflight or |
| | Critical Question | Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with long-duration flights result in permanent reflex deficits? | How do circadian rhythm cycles and sleep influence performance and interact with the space environment to affect ability to accomplish mission goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity? | What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological changes incurred in space affect task performance? | Of the various countermeasures available to combat adverse cardiovascular effects on long-and short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. | What are the specific mechanisms underlying the orthostatic hypotension observed after flight? What are the effective countermeasures for this? | What is the relationship between cardiovascular response and exposure to varying gravity levels (force, internal frequency, and time interval)? there a threshold? | What is the time course and extent of muscle atrophy during either prolonged spaceflight or unloading? |
| | | Will the decrease in afferent input vestibular, proprioceptive and sor systems associated with long-dura result in permanent reflex deficits | How do circadian rhythm cycles an performance and interact with the environment to affect ability to acc goals? What countermeasures (e.g. pharmacology, lighting, etc.) can be improve performance and product | What are the best psychophysiolog of effective performance variation i environment? In what way do phychanges incurred in space affect tarperformance? | Of the various countermeasures avai combat adverse cardiovascular effect and short-duration missions, which a effective, when and how should they and in what sequence? These include limited to LBNP, fluid anti-g rehydra centrifugation, and exercise. | What are the specific mechanisms u orthostatic hypotension observed at What are the effective countermeas | What is the relationship between c response and exposure to varying (force, internal frequency, and timithere a threshold? | What is the time course and extent or atrophy during either prolonged spa unloading? |
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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

Table 6

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table 6

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| 5 | ৪ | ខ | 8 | 3 | C1 C2 C3 C4 C5 Critical Question | Quest# | C | `` | 2 3 | 3 4 | 2 | 9 | 2 | 8 | 6 | 10 | 11 | 12 | 13 | 14 | 15 1 | 6 1 | 7 | 18 G | Group w/ | | other | Disc | |
| | 8 | ဗ | 4 | | Is bone loss reversible in terms of mass, utra- and micro-structural organization, and microstructure? To what extent do irreversible | 909 | 2 | 6 | 2 | - | - | 6 | × | × | × | × | | × | | Ť T | _ | - | - | <u>κ</u> | ^ | | | | |
| | | | | | architectural adaptations affect structural integrity? | | | | | | | | | | | | | | | | | | | | | | | | |
| | * | <u> </u> | 4 | | How does mechanical stress and changes in stress contribute to bone and connective tissue formation? Are stress and/or changes in stress | 5c8 | N | ~ | 2 | | - | ಣ | × | × | × | × | × | × | | | | | _ | | | | | | |
| | 4 | | • | | required for continued structural integrity? | | | | | | | | | | | | | | | | | | | | | | | | |
| | N | , , | 4 | | What are the critical characteristics or components of normal daily tissue stress and strain histories that require how and connection | ဥပဓ | ~ | ~ | م | | | ო | <u>×</u> | <u>× </u> | × | × | × | | | • | | | | က် | ^ | | | | |
| | | · | | | tissue development, maintenance, and adaptation? How are these characteristics affected by microgravity? | | | | | | | | | | | | | | | | | <u></u> | | | | | | | |
| · | * | - | 4 | | How are regional changes in bone and connective tissue related to regional changes in muscle tissue? | 5c10 | N | 8 | - 2 | | | ო | × | × | × | × | × | | | | | | _ | က် | ^ | | | | |
| | N | - | 4 | | How are neuromuscular activation patterns and musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to 1-0? | 5c11 | N | α | 2 | | - | ო | × | × | × | × | × | | | | _ | - | - | | က် က | œ | | | |
| | | | 4 | | What are the patterns of in-vivo mechanical loading (e.g., tissue strain, stress, strain rate, stress rate)in normal and low-o environments? | 5d1 | N N | <u> </u> | | - | | n | <u>×</u> | × | × | _× | | × | | | | - | | <u> </u> | 7, | œ | | | |
| | ۲۵ | | 4 | | What are the bone and connective tissue markers of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used | 5d3 | ~ | <u>8</u> ع | ~ | - | - | ო | × | × | × | × | | × | | - 8 | | - | - | က် | 7, 6 | 6 0 | | | |
| - | | | | | to investigate and predict regional changes in bone metabolism? | · | | | | | | | | <u>-</u> | | | | | | | · | | | | | | | | |

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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Table

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| | Question Quest# | 5d6 2 | Are there specific load histories that affect the 5d7 2 macromolecular assembly of connective tissues? | What are specific signal transduction processes 5d8 2 relevant to the modulation of structural molecules during altered load histories? | 662 2 | 6b3 2 | 6b5 2 ation | 6e2 2 avity | BIII13 |
| | Question Quest# | 5d6 2 | Are there specific load histories that affect the 5d7 2 macromolecular assembly of connective tissues? | What are specific signal transduction processes 5d8 2 relevant to the modulation of structural molecules during altered load histories? | 662 2 | 6b3 2 | 6b5 2 ation | 6e2 2 avity | BIII13 |
| | Question Quest# | 5d6 2 | Are there specific load histories that affect the 5d7 2 macromolecular assembly of connective tissues? | 5d8 2 | What are sensory inputs and coordination of 6b2 2 muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | What are the optimal countermeasures for motor 6b3 2 readaptation to partial-g or 1-g after adaptation to microgravity? | What adaptive processes modify motor control 6b5 2 systems? What is the dynamic range of adaptation of motor responses in altered states of gravity? | If an on-board centrifuge is used as a 6e2 2 countermeasure (physiological system maintenance), will going from 1-g to microgravity cause repeated maladaptions? | What are the joint effects of radiation and microgravity? — How do neoplasms common to chronological aging relate to limitation of cell lifespan and susceptibility to abnormal growth regulation under altered gravitational fields? |
| | Question Quest# | * What key elements of bone and connective tissue 5d6 2 structural assembly impact the biomechanical properties? | Are there specific load histories that affect the 5d7 2 macromolecular assembly of connective tissues? | * What are specific signal transduction processes 5d8 2 relevant to the modulation of structural molecules during altered load histories? | *3 4 What are sensory inputs and coordination of 6b2 2 prosture outcomes organized for generation of posture and locomotion before, during, and after flight? | *3 What are the optimal countermeasures for motor 6b3 2 readaptation to partial-g or 1-g after adaptation to microgravity? | * What adaptive processes modify motor control 6b5 2 systems? What is the dynamic range of adaptation of motor responses in attered states of gravity? | 4 If an on-board centrifuge is used as a 6e2 2 countermeasure (physiological system maintenance), will going from 1-g to microgravity cause repeated maladaptions? | What are the joint effects of radiation and microgravity? — How do neoplasms common to chronological aging relate to limitation of cell lifespan and susceptibility to abnormal growth regulation under altered gravitational fields? |
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| ច | 8 | ខា | 3 | 8 | C1 C2 C3 C4 C5 Critical Question | Quest# | Cr | 1 2 | 3 | 4 | 5 6 | 14 | <u></u> | 6 | 100 | E | 12 | 13 | 1 | 1 | 6117 | ٩ | _ | \mathred{m} | 1 3 | 100 | |
| _ | N | | 4 | | What are the effects of the space environment on sleep, sleep cycles, or the generation, expression (period, phase, amplitude and/or waveform), and entrainment of metabolic, endocrine, reproductive, and/or hebavioral circulation that are | 2a1 | 6 | 3 | - | 2 | 2 | × | | × | × | | | | - | - | · - | | | 4, 5, | 6, 7 | | 28 |
| | | <u> </u> | 4 | | which result from altered gravity and which result from altered gravity and which result from other environmental factors? What are the effects of exercise on circadian rhythms and sleep? What pharmacological and nonpharmacological (e.g. light, exercise) agents can be used to reset the human biological clock? What are the effects of routing administration. | 2a6 | e 8 | <u> </u> | N | N | | <u>×</u> | <u>×</u> | × | × | | × | | - | - | | - | κ, 4 | ., 5, | 6, 7 | | |
| | - 3 | m | | | pharmacological agents in space on circadian rhythms and sleep? Does the well documented decrease in red blood cell mass termed "anemia of space flight" represent a normal microgravity-associated adaptive process (self-limiting) or a transient | 201 | ω 4 | | N | М | <u>ල</u> ව | × | × | × | × | × | | | - | | - | - | 7 , | _ | | | |
| | <u> </u> | | | | are are | 2c3 | | N | ო | ც | <u>ო</u> | × | × | × | × | | | | | _ | - | Q | 4, જ્ | , 7, | ω | | |
| | | | - | | they of sufficient magnitude or duration to pose an unacceptable medical risk and warrant the development of countermeasures (prophylactic or therapeutic)? Formulate mathematical and computer models of tissue adaptation and cellular transient response to altered load histories? | | | | | | | | | | | | | | | | | | | | | | |

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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Table 6

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table 6

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| | ĕ∣ | Are there appropriate animal and/or computer models for studying each functional element of pulmonary adjustments to microgravity? What is the relationship, if any, between the pulmonary adjustments to space flight and those occurring in Earth-based models such as bedrest, immersion, and head-down tilt? | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in resp to unloading? | What are the circuitry and signals in the vestibulance of and brainstem that generate a gravito-inertial frame of reference? What are the roles of the different regions of the cerebellum? | What is the distribution of receptors for anti-motion sickness drugs in central vestibuli pathways? | What models of sensory-motor transformation be used to predict motor behavior best in alter gravitational states? |
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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table 6

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| gravity and/or affected by microgravity: the expression and regulation of genetic information; cell division; cell differentiation; signal transduction, including signal-membrane dynamics; interactions, membrane-effector interactions, and signal-effector linkage; membrane dynamics; intracellular transport; secretion; alternate pathway regulation; and cell-to-cell communication? The importance of selecting cells and cell lines that can provide interpretable results bearing on precise questions cannot be overemphasized. How will altered gravitational fields and vectors change the information content of the three-dimensional microenvironment of the cells (stroma and matrix connections)? How does microgravity affect these signals under both homeostasis and challenge? Representative challenges would be wounding of dermal fibroblasts and keratinocytes (or epidermal/dermal wounding in vivo), differentiation of microvessel endothelial cells in vitro (or growth of the microvasculature in vivo, particularly following wounding or tumor implantation), and application of stress to active |
| osteoblasts (or bones in vivo). How long can single cells cope with changes in |
| these effects persist after return to unit gravity? |

Table

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| W | <u>წ</u> | <u> </u> | | What structural and morphometric alterations will occur in the extracellular matrix, the connective tissue, and the musculoskeletal systems in long term spaceflight? | 81118 | 4 | - | | | 0 0 | n n | | | | - - × | - × | 2 - 3 | 4 | | | _ | 1 8 1 9 <u>0</u> 9, | Group 3, 8, 1 | `≩ | other | Disc |
| <u> </u> | 4 | | · | result in altered differentiation of 19d tissue compesition? ellular mechanisms whereby hair celeratory information, amplify signal transmission? Is there a suism that is the transmission? | 8IVb1 | 4 | 8 | ٥. | <u>.</u> | ٠. | ٠. | × | × | × | × | × | | | | | | <u> </u> | 9 9 | | | |
| 8 | <u>ო</u> | | | ds ne, | 8Vb5 | 4 | - | - 2 | | N | ო | × | × | <u>×</u> | | × | | | | | | | | | | |
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| <u> </u> | | | | subcellular mechanisms involved in adaptation to aftered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | 8VI2 | 4 ω | - | | - | ო | - | × | <u>×</u> | × | × | × | | | | | | | | | | |
| N | <u>ო</u> | | | | 8VI6 4 | - | - | | _ | N N | ж ю | × | × | × | | × | | | | | | _ ^ | | | | |
| N | ტ | 4 | | of space-induced endocrine on of other homeostatic ascular, central nervous tion, thermoregulation, gastrointestinal system, and | 2b1 | ო | rv | N | N | N | <u>×</u> | × | × | × | × | × | | | | · · · · · · · · · · · · · · · · · · · | | က် | 4, . R, | 6, 7 | | |
| | | ╛ | 4 | energy metabolism)? | | _ | | | | | _ | | | | | _ | _ | _ | | _ | | _ | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science: Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality 9 Table

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| 5 | 3 | 3 3 | 3 . | 3 | of microgravity on renal | 214 1 | <u> </u> - | 2 | 2 2 | 2 | 2 | × | × | × | × | × | _ | _ | - | - | <u></u> _ | _ | 4 | | | | |
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| | | | | | progressive; Are triey level slute; Are tried differences in filtration, reabsorption, secretion, | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | and excretion? | | | | | | _ | > | > | > | > | <u> </u> | ` | | * | _ | _ | _ | 9 | | | | |
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| | | | | | extravehicular activity (EVA) at various levels of | | | | | _ | | | | | | | | _ | | | | | | | | | |
| | | | | | gravity (e.g., microgravity, planetary surface | | | | | _ | | | | | | | | _ | | | | | | | | | |
| | | | | | exploration)? What factors influence the | | | | | _ | | _ | _ | | | | | _ | | | | | | | | | _ |
| • | | | | | occurrence, magnitude, and sequence of these | | | | | _ | | | | | | | | | | | | | | | | | _ |
| | | | | | responses? | | | | | | | | | _; | ; | | | | ç | • | _+ | _ | 2 | r. | 7 | | |
| _ | | * | | | Following long-term space flight, are there delayed | 3a12 1 | ß | S | . | 1 | <u>ო</u> _ | <u>×</u> | | <u>×</u> | <u> </u> | _ | <u> </u> | | 4 | | _ | _ | _ | | | | _ |
| | | | | | or persistent consequences, either beneficial or | | | | | | | | | | | | | _ | | _ | | | | | | | _ |
| | | | | | harmful? As a corollary, are there appropriate | | | | | | | | | _ | | | | _ | _ | | | | | | | | _ |
| _ | | | | | rehabilitative measures that should be applied both | | | | | _ | - | | _ | | | | _ | | | | | | | | | | |
| | | | | | in the near-term (hours to days) and long-term | | | | _ | | _ | | | | | | | | | | _ | | | | | | _ |
| | | | | | (months to years) after flight? | | | | | | | _ | _ | | | | — ; | | | | • | • | 1 | | | | |
| | ٥ | <u>س</u> | 3 * 4 | | Does the atrophy from unloading make muscle, | 5a9 1 | 7 | ၈ | 7 | ` | <u>၈</u> | <u>×</u> | <u>×</u> | <u>×</u> | × | | <u> </u> | | | _ | | | | | | | |
| | | | | | tendon, and the myotendinous junction more | ** | - | | | | | | _ | | | | _ | _ | | | _ | | | | | | |
| | | | | | susceptible to injury or damage on resuming | | | | | | | | | | | | | - | | | | | | | | | |
| | | | | | normal weight-bearing states? | | | | | | | | | ; | | | | | | _ | _ | | 7 4 | | | | |
| | | <u>.</u> | 4 | | What potential risks does bone loss present to the | 5c4 1 | ო | ო | _ | 2 | | <u>×</u> _ | <u><_</u> | <u><</u> | <_ | | - | | - | | _ | • | <u>. </u> | | | | |
| _ | | | | | development of bone fractures, hypercalcemia, | | | | | | | _ | _ | | | | | | | | | | | | | | |
| | | | | | metastatic calcification, and renal stone | | | | | - | _ | _ | | | | | | | | | | | | | | | |
| _ | - | | | | formation? | | | | | | | | | | _; | | > | | | | • | <u> </u> | 4 6 | | | | |
| | | က | * | | What is the nature of space flight-induced changes | 2e14 2 | <u>ო</u> | က | 8 | _ | 2 | <u>×</u> - | <u>×</u> _ | <u>×</u> _ | <u> </u> | | <u> </u> | | | | | | _ | | | | |
| | | | | | in effect of vasoactive drugs? | | | | | | | | | | | | ; | | | _ | | _ | _ | ď | | | |
| _ | | က | * | | What is the nature of space flight-induced effect of | 2e15 2 | က | ო | 7 | - | 2 | <u>×</u> - | <u>~</u> | <u>×</u> _ | <u> </u> | | <u> </u> | | | | | | _ | | | | |
| | | | | | pharmocokinetics of drugs? | | | | | | | | | | _> | | | | | | | _ | | · | | | |
| | | * ღ | 4 | | What are the effects of space flight and/or EVA on | 2g1 2 | 2 | α_ | 2 | 7 | <u> </u> | <u>×</u> - | <u>×</u> _ | <u>< </u> | <u> </u> | | | | | | | | | , | | | |
| | | | | | thermoregulation processes and heat exchange? | | ┥ | 4 |] | | 1 | 1 | ┪ | + | 4 | 4 | | 1 | 1 | 1 | ┨ | \mathbf{I} | | | | | |

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| 1 | 2 | Does the extent of adaptation affect postflight orthostatic tolerance? | Since microgravity atters blood pressures and flows to some tissues, what are the structural functional consequences in these various tissu | and organ systems with long-duration flights? How completely and how well does injured muscle repair in microgravity? | How will the reproductive status of premenopausa female crewmembers be managed to minimize the risk of pregnancy, osteoporosis, and hemorrhage from ruptured follicles during ovulation? What is the role of gravity in developmental biology? — Does the developmental omogeny of animals raised through more than one life cycle under a changed gravity field differ from the 1-g classical pattern? Does this altered pattern reside in the genome, or is it relayed from hormonal and stromal interactions? — Are there critical windows of susceptibility for developmental processes, or is development affected in a gradient? — If gravity-related effects exist, can they be reversed in the short- or long-term? — What will be the result of gravity-induced dys-synchrony (temporal or hormonal) during | ğ |
| Ŀ | C Critical | 8 등 | 활출출 | 로 된 현 | How will the reproductive status of premenor female crewmembers be managed to minimizer risk of pregnancy, osteoporosis, and hemorth from ruptured follicles during ovulation? What the role of gravity in developmental biology? — Does the developmental omogeny of animal raised through more than one life cycle under changed gravity field differ from the 1-g class pattern? Does this altered pattern reside in tigenome, or is it relayed from hormonal and stromal interactions? — Are there critical windows of susceptibilit developmental processes, or is development affected in a gradient? — If gravity-related effects exist, can they b reversed in the short- or long-term? — What will be the result of gravity-induced dys-synchrony (temporal or hormonal) during | development? |
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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table 6

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| | What are the effects on the male and female germ | cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell | 5 | rentiation of other individual cell types? Can altered grayities affect fertilization, and do | these results indicate more general mechanisms of | <u> </u> | Which responses are transmitted maternally, | and which are findflisted to the developing chiefler. What are the results of altered gravity fields on | the axis polarity and symmetries of the zygote? | Are there gravity effects that can terminate in | | | mechanisms (e.g. endocrine, organ, circulatory, | oo to | | # | <u>د</u> | | drugs | ╆. | ⊆ 1 | 9 | |
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| İ | _ £ | cells of protracted, chronic, low dose exposi space radiation outside the Van Allen belts? events in gametogenesis and early germ cell | maturation are gravity sensitive, and how can these results relate to the proliferation and | differentiation of other individual cell types? Can attered gravities affect fertilization, an | Sult | membrane alteration in individual cells? | <u>ਨ</u> - | <u> </u> | 8 | Ę | changes of gene activation? | How does gravity affect compensatory | nism vite | with growth stages? What is gravity's effect | wound healing? | Are there in-vitro tests that reliably predict | decreases in immune function in space flight? | What are the pharmacokinetics (absorption, | distribution, metabolism, and elimination) of | likely to be used in space? Which methods of | administering drugs are the most effective in | providing a predictable response during space | |
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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| E 4 4 9 8 E 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 | the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | | | | | | | | | | | | | | | | | | | | | | | | |
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| 2 2 2 8 8 8 1 1 2 2 1 1 1 1 1 1 1 1 1 1 | 4 | What are the time course and magnitude of the diuresis, natriuresis, and kaliuresis resulting exposure to hypogravity? | What are the time course and magnitude of the diuresis, natriuresis, and kaliuresis resulting exposure to hypogravity? | _ | _ | | 216 | | | | | | | | | | | <u>×</u> | | | | | - | | | 10 | | | |
| 3 | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations, particle size profiles, and bacterial contaminations? Do these factors constitute a health hazard? | | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations particle size profiles, and bacterial contaminations? Do these factors constitute a health hazard? | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations particle size profiles, and bacterial contaminations? Do these factors constitute a health hazard? | In the environment of microgravity, does the absence of sedimentation cause deeper penetration by aerosol particles in the lung? In the spacecraft environment, what are the aerosol concentrations particle size profiles, and bacterial contaminations? Do these factors constitute a health hazard? | | 3925 | | | | | ···· | | | | | | | | | - | - | | - | | | | | |
| 3 8 6 7 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 | 3 * 5 What is the role of gravity on thirst and feeding behaviors (appetite, taste preference, and thresholds)? | ٠ د | | | What is the role of gravity on thirst and feeding behaviors (appetite, taste preference, and thresholds)? | | 8Vb3 | | | | | | | | | | | | | | - | ~ | 8 | - | - | | | | |
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| | For the well documented changes in calcium metabolism associated with space flight, what are the direct and indirect consequences for electrical, mechanical, and vascular events in the hear? | | | | For the well documented changes in calcium metabolism associated with space flight, what are the direct and indirect consequences for electrical, mechanical, and vascular events in the hear? | _ ෆ | 3a20 3 | | | | | -0 | | | | | | | | | 8 | - | - | + | 8 | | | | |

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table

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| Quest* | ice flight affect pulmonary aging or disease 3b5 | processes commonly found in adults in a 1-g environment? How is subclinical pulmonary pathology (e.g., incipient bronchospasm, early | emphysema) affected by space flight? Do these same questions apply to healing processes in the | st and 2f9 | 3a24 | • | these changes play in the adaptation to microgravity and return to normal gravity? | Does redistribution of blood volume and flow during 3a27 space flight affect pH, PO2, or PCO2 in tissues of | any organs and vice versa? Are there cellular and subcellular changes in 3a28 | function in the heart? Are there changes in myocardial contractile proteins? Is there a change | in excitation-contraction coupling mechanisms induced by space flight? | What are effects of weight bearing on 5a11 | What is the role of thalamo-cortical systems in 6a2b | generating a gravito- inertial frame of reference? What neuronal models can be used to understand 6a4 | central processing and adaptation in aftered |
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| #twenO_ | ice flight affect pulmonary aging or disease 3b5 | processes commonly found in adults in a 1-g environment? How is subclinical pulmonary pathology (e.g., incipient bronchospasm, early | emphysema) affected by space flight? Do these same questions apply to healing processes in the | lung: What are the mechanisms regulating thirst and 219 | electrolyte appetite during space flight? What is the nature of microgravity-associated 3a24 | changes in the autoregulatory mechanisms of arterioles, venules, and lymphatics? What role | these changes play in the adaptation to microgravity and return to normal gravity? | • Does redistribution of blood volume and flow during 3a27 space flight affect pH, PO2, or PCO2 in tissues of | any organs and vice versa? Are there cellular and subcellular changes in 3a28 | | in excitation-contraction coupling mechanisms induced by space flight? | • What are effects of weight bearing on 5a11 | * What is the role of thalamo-cortical systems in 6a2b | generating a gravito- inertial frame of reference? What neuronal models can be used to understand 6a4 | central processing and adaptation in altered |

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Critical Questions That Would Utilize The SSF Centrifuge Facility

Table 6

Listed by Category and Criticality

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| | Question | 5 * What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | 5 * How do altered biological rhythms associated with long-term space flight affect hormone secretion and vice versa? | 5 • What are the time courses and magnitudes of changes in the erythropoietic system during space flight? | 5 * What is the relationship between altered hematocrit, renal function, and erythropoietin levels in micro-, partial, and unit gravity? | 4 5 "What are the major factors and associated mechanisms that contribute to the "anemia of space flight"? — What controls the alterations in red cell production or survival? — Does the loss of red cell mass result from an impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? 4 5 "Is the "anemia of spaceflight" related to a direct effect of microgravity or other space-flight-induced stressors on bone marrow |
| | | 5 * What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | 5 * How do altered biological rhythms associated with long-term space flight affect hormone secretion and vice versa? | расе | oietin ty? | 5 * What are the major factors and associated mechanisms that contribute to the "anemia of space flight"? — What controls the alterations in red cell production or survival? — Does the loss of red cell mass result from an impairment of the red blood cell proliferation process or to differential margination, reticuloendothelial sequestration, cell death, or other mechanisms? 5 * Is the "anemia of spaceflight" related to a direct effect of microgravity or other space-flight-induced stressors on bone marrow |

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| | Does space flight affect the humoral or cell-mediated immune functions, nonspecific immunity, or immune surveillance capabilities of space crews in a manner that would expose them to unacceptable medical risk while on a mission, upon return to Earth, or as a consequence of repeated mission exposure? | What are the effects of space-flight-related factors, (e.g. bone demineralization and light spectrum) on nutritional requirements? | What changes in carbohydrate/lipid metabolism occur during space flight? Are they modified by dietary intake? | 5 To what extent does the qastrointestinal system modify electrolyte and fluid balance control during space flight? | * How does the regulation of body temperature change during space flight? How do these changes affect the response to thermal load? | * How are changes in body temperature or its regulation correlated with metabolic rate and energy expenditure? | activity function play a role in regulating calcium or antigravity muscle growth and function during development and aging and exposure to attered |
| Critical Question | Does space flight affect the I cell-mediated immune functic immunity, or immune surveil space crews in a manner that to unacceptable medical risk upon return to Earth, or as a repeated mission exposure? | What are the effects of space-flight-relactors, (e.g. bone demineralization and spectrum) on nutritional requirements? | What changes in ca occur during space dietary intake? | To what extent doe modify electrolyte a space flight? | How does the regulation of body tem change during space flight? How do t affect the response to thermal load? | How are changes in regulation correlated energy expenditure? | Does a change in oto activity function play or antigravity muscle development and agin |
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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality Table 6

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| | 8la1 | 8la2 4 | 8la3 4 | 8la5 | 81b7 | 8Ic3 | 81c6 | 8 18 4 | 811b2 | 81lb4 owth as t are | Zeaz. |
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| Question Quest# C | 8la1 | 81a2 | 8la3 | 8la5 ogravity? | 81b7 | 8Ic3 | 81c6 | 811a4 rensing ect sence | 811b2 | 81lb4 owth as t are | intacellular paulways of clearlicary inculated signal transfer, and the nuclear envelope/nuclear natrix to functional response? |
| Question Quest# C | 8la1 | 81a2 | 8la3 | 8la5 ogravity? | * How do plants adapt to microgravity? | 8Ic3 | *What are the mechanisms by which transport 81c6 systems are polarized in plants grown in space? | 811a4 rensing ect sence | * Research indicates that resting/active cells are 811b2 not measurably affected by changes in gravity. What is responsible for the difference in responsiveness between resting and active cells? | 81lb4 owth as t are | signal transfer, and the nuclear envelope/nuclear matrix to functional response? |
| Question Quest# C | e mechanisms that underlie gravity 81a1 | ents in gravity 81a2 | | 8la5 | 81b7 | ant on 81c3 | 81c6 | 8 18 4 | 811b2 | 811b4 | signal transfer, and the nuclear envelope/nuclear matrix to functional response? |
| Question Quest# C | 8la1 | 81a2 | 8la3 | 8la5 ogravity? | * How do plants adapt to microgravity? | 8Ic3 | *What are the mechanisms by which transport 81c6 systems are polarized in plants grown in space? | 811a4 rensing ect sence | * Research indicates that resting/active cells are 811b2 not measurably affected by changes in gravity. What is responsible for the difference in responsiveness between resting and active cells? | 81lb4 owth as t are | signal transfer, and the nuclear envelope/nuclear matrix to functional response? |
| Quest# C | 8la1 | 81a2 | 8la3 | 8la5 ogravity? | * How do plants adapt to microgravity? | 8Ic3 | *What are the mechanisms by which transport 81c6 systems are polarized in plants grown in space? | 811a4 rensing ect sence | * Research indicates that resting/active cells are 811b2 not measurably affected by changes in gravity. What is responsible for the difference in responsiveness between resting and active cells? | 81lb4 owth as t are | signal transfer, and the nuclear envelope/nuclear matrix to functional response? |

Table 6

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| 5 | 8 | <u>بر</u> | ₹ | C1 C2 C3 C4 C5 Critical | tical | Question | Quest# | 5 | _ | 2 | 4 | 10 | ဖွ | 7 | 00 | O | 10 | 11 | 12 | 13 | 14 | 151 | 161 | 171 | 8 | Group | / ₩ | othe | r Disc | ပ္တ |
| | | ··· - | u) | F + How | r are c icellula | 5 * How are cell-cell and cell-surface contacts in amulticellular systems affected by microgravity? | 81156 | 4 | | | | | | × | × | × | × | × | | | Ť | - | 2 | - | | c, | | 8, 1 | | : [|
| | | | 4D | 5 * Where differ direct | rences | | 811b7 | 4 | | | | | | × | | × | × | × | × | | | - | 2 | 2 | 4, | rų, | 7, 8 | 8, 11 | | |
| | | | | may may med | microgravity a may reflect th mechanisms? | microgravity and responses at a later time, that may reflect the operation of compensatory mechanisms? | | | | | | | | | | | | | | | | | | | · | | | | | |
| | | | 47 | F. How of of of | r can gurbing | 5 * How can gravity be used as a research tool in perturbing cell structure/function in the absence of other effectors? | 811c2 | 4 | | | | · · · · · · · · · · · · · · · · · · · | | × | × | × | × | × | × | | - | | 2 | <u></u> | | | | | | |
| | | | 2 | * S be d | sh devi | 5 * Which developmental mechanisms have evolved to be dependent on the 1-g gravity field and vector? | 81112 | 4 | | | | | | × | × | × | × | × | × | | | | | | 4, | , 7, | œ | | | |
| 7 | 01 | | 22 | 5 * Whic gravi | sh orge ity fiel | * Which organ systems are dependent on the 1-g gravity field and vector? | 81113 | 4 | | | | | | × | × | × | × | × | | | | | | | 4 | , 5, | 7, 8 | _ | | |
| · · · · · · · · · · · · · · · · · · · | | | 32 | Cons | siderini es, be | 5 * Considering development as a series of stages or phases, beginning with pattern specification, and | 81115 | 4 | | | | | | × | × | × | × | × | × | | | - 2 | | | - α | | | | | |
| | | | | progravi | ressing ity affe | progressing through differentiation, how will gravity affect selected phases in animals that | | | | ······································ | | | | | | | | | | - | | | | | ** | | | | | |
| | | | | <u> </u> | How w | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | postu | ogravn ural oc | postural control required in mating? | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | gravit | will aquity as | will adulate animals perceive and respond to gravity as do their terrestrial counterparts? | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | in bo | I hose anim in both env for study. | I hose animals which pursue different life stages in both environments may be particularly valuable for study. | | | | | | | | | | | | | | | | | | <u> </u> | | | | | | |
| <u> </u> | | | r. | At wit circad respe | hat sta dian ri | 5 * At what stage can we observe perturbations of circadian rhythms, both temporally and with respect to differentiation state? | 81116 | 4 | | | | | | × | | × | × | × | × | | | | 01 | - | <u>რ</u> | 4 | | | | · · |

Critical Questions That Would Utilize The SSF Centrifuge Facility
Listed by Category and Criticality

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| F | 6118 | 81110 4 | | | 4 4 | 81112 | 8lVa1 4 | 81Va2 4 | 8IVa3 4 | 81Va4 4 |
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| C r 1 | 81119 I target ed | 4 4 4 | | tered gravity | 811111 on | 811112 to ed | | 8IVa2 | 81Va3 | 81Va4 gravity |
| C r 1 | 81119 I target ed | 4 4 4 | | altered gravity | 811111 on | 811112 to ed | | 8IVa2 | 81Va3 | 81Va4 |
| C r 1 | 81119 I target ed | 4 4 4 | | to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
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| C r 1 | 81119 I target ed | 4 4 4 | | sensitive to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Quest# Cr1 | 81119 I target ed | 4 4 4 | | ost sensitive to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Quest# Cr1 | 81119 I target ed | 4 4 4 | | most sensitive to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Quest# Cr1 | 81119 I target ed | 4 4 4 | | the most sensitive to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| C r 1 | 81119 I target ed | 4 4 4 | | are the most sensitive to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Question Quest# Cr11 | 81119 I target ed | 4 4 4 | | is are the most sensitive to altered gravity | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Question Quest# Cr11 | 81119 I target ed | 4 4 4 | | tems are the most sensitive to altered gravity (urbations? | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Question Quest# Cr11 | 81119 I target ed | 4 4 4 | | systems are the most sensitive to altered gravity serturbations? | 811111 on | 811112 to ed | 8IVa1 | 8IVa2 | 81Va3 | 81Va4 |
| Question Quest# Cr11 | 81119 I target ed | * How will parent-young interactions be altered in 811110 4 the space environment? — Will hatching or parturition occur normally? — What will he the effects on largation subding | and related parent- young bonding mechanisms? — In the period of rapid post-natal growth, which | systems are the most sensitive to altered gravity perturbations? | 811111 on | 811112 to ed | gravitational effects? Is gravity a continuum in terms of 8IVa1 stimulus/response? | 8IVa2 | 81Va3 | 81Va4 gravity |
| Question Quest# Cr11 | oond 81119 ected target vrnined | 4 4 4 | | systems are the most sensitive to altered gravity perturbations? | 8111 | uce responses in cultured 81112 seen in chronologically aged om accelerated aging cent cells in vitro? | 8IVa1 | y in the evolution of 81Va2 | rties and fundamental 81Va3 gravity sensors to adapt ent? | 81Va4 |
| Question Quest# Cr11 | 81119 I target ed | * How will parent-young interactions be altered in 811110 4 the space environment? — Will hatching or parturition occur normally? — What will he the effects on largation subding | | systems are the most sensitive to altered gravity perturbations? | 811111 on | 811112 to ed | gravitational effects? Is gravity a continuum in terms of 8IVa1 stimulus/response? | 8IVa2 | 81Va3 | 81Va4 gravity |
| Question Quest# Cr11 | 81119 I target ed | * How will parent-young interactions be altered in 811110 4 the space environment? — Will hatching or parturition occur normally? — What will he the effects on largation subding | | systems are the most sensitive to altered gravity perturbations? | 811111 on | 811112 to ed | gravitational effects? Is gravity a continuum in terms of 8IVa1 stimulus/response? | 8IVa2 | 81Va3 | 81Va4 gravity |
| Question Quest# Cr11 | 81119 I target ed | * How will parent-young interactions be altered in 811110 4 the space environment? — Will hatching or parturition occur normally? — What will he the effects on largation subding | | systems are the most sensitive to altered gravity perturbations? | 811111 on | 811112 to ed | gravitational effects? Is gravity a continuum in terms of 8IVa1 stimulus/response? | 8IVa2 | 81Va3 | 81Va4 |
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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| ý | Question Quest# C | 81Vb2 | *How do nerve fibers innervating gravity sensors 8IVc2 convey information about linear acceleratory forces acting on the system? What is the basis of neural coding? | Is there a fundamental principle of gravity sensor BIVc4 information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | BIVc5 nent, bstrate? | 81/41 | 81743 | 81Vd5 |
| ý | Question Quest# C | *What is the specific role of calcium in information 8IVb2 processing by gravity sensors, and has this role undergone evolutionary expansion or diminution? | 81Vc2 | 8IVc4 | 8IVc5 | 8IVd1 | 81Vd3 | 81Vd5 |
| ý | Question Quest# C | 81Vb2 | *How do nerve fibers innervating gravity sensors 8IVc2 convey information about linear acceleratory forces acting on the system? What is the basis of neural coding? | *Is there a fundamental principle of gravity sensor 8IVc4 information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | BIVc5 nent, bstrate? | * What are the principles of organization, and the INVd1 inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are placed in altered-g environments? Are there restrictive mechanisms in some species that | prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) Will animals bred in microgravity or hypergravity 8IVd3 be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are tuned to a gravitational | extreme? Is it Earth's environmental position, off an extreme, that permits adaptive responses? * Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? |
| ý | Question Quest# C | 81Vb2 | *How do nerve fibers innervating gravity sensors 8IVc2 convey information about linear acceleratory forces acting on the system? What is the basis of neural coding? | *Is there a fundamental principle of gravity sensor 8IVc4 information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | BIVc5 nent, bstrate? | * What are the principles of organization, and the INVd1 inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are placed in altered-g environments? Are there restrictive mechanisms in some species that | prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) Will animals bred in microgravity or hypergravity 8IVd3 be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are tuned to a gravitational | extreme? Is it Earth's environmental position, off an extreme, that permits adaptive responses? * Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? |
| ý | Quest# | 81Vb2 | *How do nerve fibers innervating gravity sensors 8IVc2 convey information about linear acceleratory forces acting on the system? What is the basis of neural coding? | *Is there a fundamental principle of gravity sensor 8IVc4 information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | BIVc5 nent, bstrate? | * What are the principles of organization, and the INVd1 inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are placed in altered-g environments? Are there restrictive mechanisms in some species that | prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) Will animals bred in microgravity or hypergravity 8IVd3 be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are tuned to a gravitational | extreme? Is it Earth's environmental position, off an extreme, that permits adaptive responses? * Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Listed by Category and Criticality

| C1 C | 120 | 8 | 4 0 | C1 C2 C3 C4 C5 Critical Question Que | Quest# C | r 1 2 | <u>ω</u> | 4 | 2 | 9 | 4 | 8 | 6 | 101 | = | 2 | 13 14 | 4 1 ! | 15 16 | 6 17 | 7 18 | ğ | dno | 17 18 Group w/ other | her [| Disc |
|------|----------------|---|----------|--|----------|--------|----------|------|----------|---|---|---|---|-----|---|---|--------------|--------------|--------------|--------------|--------------|----------|-----|----------------------|-------|------|
| | - | | 5 | 5 • Does development of a gravity receptor in an altered-g environment affect the ability of the animal to mature and reproduce? | 10 4 | | <u> </u> | | | | × | | × | × | × | | | - | - | | 1 | 89 | 10 | | | |
| | ٠ | | ιΩ | 5 • Would gravity sensors of animals bred in a | 92 4 | | | | | | × | | × | × | × | _ | | _ | _ | | | ω΄ | 10 | | | |
| | | | | sustained, attered gravitational environment be different structurally and functionally from those of animals bred on Earth? Would the changes be permanent? | | | | | | | | | | | | · | | | | | | | | | | |
| | | | ψ. | 6 Is there a critical time for exposure to 1-g for development of a gravity sensor with features typically associated with those of animals confined to Earth's 1-g environment? (Equal weight with 2 above) | 4, | | | | | | × | | × | × | × | | | - | - | - | - | <u>κ</u> | 0 | | | |
| | | | rc. | If there is a critical period for exposure to 1-g for normal gravity sensor development, is it essential to accomplish this to provide for future plasticity and for readaptability to Earth's 1-g? | 4 | | | | - | | × | | × | × | × | | | Y | | | _ | ω, | 10 | | | |
| | | · - · · · · · · · · · · · · · · · · · · | -C2 | S • Are there species differences in degree of susceptibility to a developmental change in an altered-g environment? | 4 | | | | | | × | × | × | × | × | × | | Ψ | | - | Ψ- | ω΄ | 5 | | | |
| | | | ις | Would animals bred for many generations in space 81Ve6 retain their adaptive ability to an altered-g force? Will this ability vary according to species? | 96 | | | | · | | × | | × | × | × | × | | | | - | - | ω | 10 | | | |
| | | | <u>ν</u> | What are the mechanisms that permit central 8IVf1 adaptation to novel inputs from gravity sensors in an attered-g environment? Does rewiring take place? | £ 4 | | | | | | × | | × | × | × | × | | - | - | Ψ | | σο | | | | |
| | , , | | ស | S • What is the importance of an interaction between 81Vf2 gravity sensor input and other sensory information in total 3-D orientation, over time, of the organism? How does this change during evolution? | 4 | | | ···· | <u> </u> | | × | × | × | × | × | × | | | | - | | 80 | ! | | | |

Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality

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| | Question Quest# Cr1 | the 8Va2 | * How does gravity affect interactions between the 8Va3 circadian system and other homeostatic mechanisms? | What is the role of gravity on closed loop regulatory systems (neuroendocrine, mechanisms, responsiveness, development)? | * How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter telease and re-uptake processes? | *What is the role of gravity in the regulation and 8Vb11 onset of reproductive cycles (vaginal opening, puberty, estrus cycles, fertilization, pregnancy, parturition, lactation, aging, life space, etc.)? | If so, how 8Vb12 | Are regulatory responses to an artificial 1-g 8Vb13 environment in space equivalent to 1-g responses on Earth? | "Is 24 hour per day 1-g exposure necessary to 8Vb14 maintain normal regulatory function? If not, what is the minimum time? What are the optimal presentation characteristics of the Cambridge. | nulus? 8VI3 ological /? |
| | Question Quest# Cr1 | the 8Va2 | * How does gravity affect interactions between the 8Va3 circadian system and other homeostatic mechanisms? | What is the role of gravity on closed loop regulatory systems (neuroendocrine, mechanisms, responsiveness, development)? | * How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter telease and re-uptake processes? | *What is the role of gravity in the regulation and 8Vb11 onset of reproductive cycles (vaginal opening, puberty, estrus cycles, fertilization, pregnancy, parturition, lactation, aging, life space, etc.)? | If so, how 8Vb12 | Are regulatory responses to an artificial 1-g 8Vb13 environment in space equivalent to 1-g responses on Earth? | "Is 24 hour per day 1-g exposure necessary to 8Vb14 maintain normal regulatory function? If not, what is the minimum time? What are the optimal presentation characteristics of the Cambridge. | nulus? 8VI3 ological /? |
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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Critical Questions That Would Utilize The SSF Centrifuge Facility Listed by Category and Criticality 9 Table

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| | | • | | | humans to altered gravity are similar and which | | | | | | | | | | | | _ | | | | | | | | | | |
| _ | _ | | _ | | mechanisms are different? | | | | | | \dashv | \dashv | 4 | \rfloor | | 1 | 1 | \dashv | \dashv | ┨ | 4 | |] | | | | |
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TABLE 7

CRITICAL QUESTIONS THAT WOULD UTILIZE A LUNAR BASE LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew 3 health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- Science Specifically enabled by Moon and/or Mars Missions.
- 5 Basic Research Not Directly Applicable to Moon and/or Mars Missions.
 - Indicates primary category of application.

CRITICALITY

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Important science which is relevant to exploration mission.

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

16.

- Science Readiness Levels
 - Only folklore of practitioners and anecdotal data available
 - Basic scientific concept formulated
 - Ground models developed, flight validation required
 - Flight validation performed
 - Countermeasures identified Countermeasures tested
 - Operational requirements established
- **Technology Readiness Levels**
 - Technology need identified
 - Technology and conceptual solution available
 - 3 Component and/or breadboard validation in laboratory environment exist
 - Flight validation performed
 - Systems/subsystem prototype demonstration in a relevant ground or space environment completed
 - System prototype demonstrated in a space environment
 - Actual system completed and flight qualified through test and Demonstration
 - Actual system "flight proven" through successful mission operations
- Schedule (information required by)
 - Near term < 5 years
 - Mid term 6-10 years
 - Far term > 10 years
- **Effort Required**
 - Substantia
 - Moderate
 - Low
- 5 Defined Sequence (Clearly defined sequential path for scientific investigation exists)
 - Yes No
- Parallel/Alternative Path (are parallel or alternative pathways appropriate)
 - Yes
- No
- 7. Ground-based
- Ground-based research required
- Spacelab
 - Spacelab would be used for research
 - **EDO** Spacelab needed for Extended Duration Orbiter
- SSF
 - Space Station Freedom would be used x

- Centrifuge
- SSF Centrifuge Facility would be used
- Free Flyer 11. Free fiver biosatellite
- 12 Lunar Base
- Lunar base would be used
- 13 Robotic Explorer
- Robotic explorer would be used
- Other Requirements
 - Requirement for flight resources other then those
- identified in 8-10 Flight Validation Required
 - Flight validation required
 - Not required
 - **Facilities Sufficient**
 - Current ground facilities (NASA Centers, Universities and provide industry) are sufficient. 1.
- Current ground facilities insufficient
- 17. Community Sufficient
 - There is a sufficient scientific community already
 - committed or recruitable
 - Scientific community is insufficient
- **Attract New Community** 18.
 - Activity will attract new scientists Activity will not attract new scientists
- Group with other disciplines (can this activity be grouped with others from different life science disciplines?)
 - No, cannot be grouped
 - Do not know at this time 3
 - Behavior, Performance and Human Factors
 - Regulatory Physiology Cardiopulmonary 5
 - 6. **Environmental health**
 - Musculoskeletzi a Neuroscience

 - Radiation Health
 - 10. Cell and Developmental Biology
 - Plant Biology
 - 12 Life Support

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Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| <u>.</u> | ر در | ო | | | | What factors should be considered (e.g. | 1d2 | - 2 | | <u>ო</u> | _ | ო | m | × | × | <u>~</u> | | • | <u> </u> | | = | | | _ | N | | | | | |
| | | | | | | maintainability, reliability, operator discretion) | | _ | | _ | | | | | | | | | | | | | | | | | | | | |
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| | | | | | | machines? | | | | | | | | | | | | | | | | | | | | | | | | |
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| | , | | | | | microorganisms in air, water, food, and surfaces? | | | | | | | | | | | | | | | | _ | _ | | | | | | | _ |
| - | _ | | | | | What will the radiation environment be within the | 7a8 | - 2 | 4 | _ | | က | က | | × | × | | × | × | × | ., | 2 | _ | _ | _ | | | | | |
| | | _ | | | | space vehicle and what factors influence the flux, | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | energy, and linear energy transfer spectra of the | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | radiation? | | | | | | | | | | | | | _ | | _ | | | | | | | | | |
| - | | | | | | How can protection against the effects of galactic | 7a9 | _ | - 2 | <u>ෆ</u> | <u>-</u> | _ | _ | × | × | × | | × × | | × | .4 | 7 | _ | _ | _ | | | | | |
| | | | | | | cosmic rays and the proton radiation of solar | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | events be improved? | | | | | | | | | | | | | - | | | | | | | | | | | |
| | | | 4 | | | How stable in storage are foods considered for | 9b11 | - | 3 | | က | _ | _ | × | | × | | | × | | | <u>-</u> - | _ | _ | ا | ე, მ, | 9 | | | |
| | | | | | | Mars mission and how can storage stability in | | | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | | | | space be increased? | | | | | | _ | | | | | | | | | - | | | | | | | | | _ |
| | | | | | | What are the safety and quality considerations | | | | | | | | | | | | | | | - | | | | | | | | | |
| | | | | | | of storage? | | | | | · | | | | | | | | | | | | | | | | | | | |
| | | | | | | What processes are feasible to use in a CELSS? | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | Are additives needed? If so, which ones? | | | | | | | | | | | | | | _ | | | | | | | | | | |
| | | | | | | What are the storage/inventory requirements? | | | | | | | | | | | | _ | | | | _ | | | | | | | | |
| | | | | | | For what types of foods will storage be | | | | | | _ | | | | | | | | | | | | | | | | | | |
| | | | | | | unnecessary? | | | | | | | | | | | | | | | _ | | | | _ | | | | | |
| | | | | | | Is there a need for packaging? If so, which | | | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | | | | products will require it? | | | | | - | | | | | | | | \neg | \neg | \dashv | \neg | | | ┨ | | ļ | l | | \neg |

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Table 7 Day

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | Question Quest# Cr11 | What food processing and storage technologies will pb12 need to be developed for space application? — How will existing and new processing and storage techniques perform in the constraints of a CELSS environment? — What differences are there in product development for space compared to land-based activities? — What are the influences of processing, cooking, and serving on — nutrient and attribute stability? — How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? | ary 9c168 1 2 and | hemical regenerative 9e425 1 2 processes required for a Mars rt system function in the space sider: If liquid-gas interfaces (e.g., for separations of liquids, solids, and separation of air, water, and s and how is it monitored to h safety and performance? |
| | Question Quest# Cr11 | What food processing and storage technologies will pb12 need to be developed for space application? — How will existing and new processing and storage techniques perform in the constraints of a CELSS environment? — What differences are there in product development for space compared to land-based activities? — What are the influences of processing, cooking, and serving on — nutrient and attribute stability? — How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? | ary 9c168 1 2 and | hemical regenerative 9e425 1 2 processes required for a Mars rt system function in the space sider: If liquid-gas interfaces (e.g., for separations of liquids, solids, and separation of air, water, and s and how is it monitored to h safety and performance? |
| | Quest# Cr1 | What food processing and storage technologies will pb12 need to be developed for space application? — How will existing and new processing and storage techniques perform in the constraints of a CELSS environment? — What differences are there in product development for space compared to land-based activities? — What are the influences of processing, cooking, and serving on — nutrient and attribute stability? — How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? | ary 9c168 1 2 and | hemical regenerative 9e425 1 2 processes required for a Mars rt system function in the space sider: If liquid-gas interfaces (e.g., for separations of liquids, solids, and separation of air, water, and s and how is it monitored to h safety and performance? |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Page 3

Table 7 C

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| CZ C3 C4 C5 Critical Question | - | - | - | - | #18 en 5 | 5 | _ | Ź | , | , | ٥ | ┪ | ┪ | ┪ | _ | _ | - | | _ | -1 | | - | 1 | - | | | - 1 | |
| Gan safe and sufficie provided for the trip current expendable sand sufficient supplie Mars mission? | Can safe and sufficie provided for the trip current expendable s and sufficient supplie Mars mission? | Can safe and sufficie provided for the trip current expendable and sufficient supplie Mars mission? | Can safe and sufficie provided for the trip current expendable sand sufficient supplie Mars mission? | Can safe and sufficient supplies of water and air be provided for the trip/stay to/at Mars? Do current expendable systems exist to provide safe and sufficient supplies of water and air for the Mars mission? | 9f1a | - | 2 | 9 | 8 | 3 | _ | × | | <u>×</u> | | | × | : **: | | - | 8 | - | - | မ (၁ | | | | |
| 3 Do systems exist to provide EVA/EHA or required for Mars surface exploration? | Do systems exist to required for Mars si | Do systems exist to required for Mars so | Do systems exist to required for Mars so | Do systems exist to provide EVA/EHA capabilities required for Mars surface exploration? | 9f6b | - | 8 | 8 | -2 | | | <u>×</u> | | | | | <u>×</u> | | | | - | | | မ မ | | | | |
| What requirements since human missions (orthogonal Mars with respect to imported from Earth | | What requirements si human missions (ort Mars with respect to imported from Earth | What requirements st human missions (ort Mars with respect to imported from Earth | What requirements should be placed on robotic and human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | 10 1 | + | | ∞ | - | <u>ო</u> | | × ¥ | | × | | <u>×</u> | × | × | | N | N | N | - | 13, | 4 | | | |
| What are the require life as they relate to vibroacoustics, lightin (privacy, recreation) | What are the require life as they relate to vibroacoustics, lightir (privacy, recreation) | What are the require life as they relate to vibroacoustics, lightin (privacy, recreation) | What are the require life as they relate to vibroacoustics, lightir (privacy, recreation) | What are the requirements for adequate quality of life as they relate to food, clothing, hygiene, vibroacoustics, lighting, and other personal needs (privacy, recreation) in spacecraft and habitats? | 10 | N | en . | - | ю — | - | 2 | × | × | <u>×</u> | | | <u>×</u> | | | | N | N | _ | 4 | | | | |
| What are the behavi | What are the behavi | What are the behavi | What are the behavi | What are the behavioral correlates of physiological changes induced by the space environment? | 101 | 0 | - | 8 | <u>د</u> | - | <u>e</u> | | × | × | | | × | | | | α | 8 | _ | <u>ري</u> بې | 4 | 5, 6 | | |
| How can traditional human toxicological c acceptable values for exposures to single including biological to conditions? | How can traditional human toxicological c acceptable values for exposures to single including biological treatments? | How can traditional human toxicological cacceptable values for exposures to single including biological to conditions? | How can traditional human toxicological c acceptable values for exposures to single including biological treconditions? | How can traditional limited-time exposure and human toxicological data be used to predict acceptable values for inhalation and ingestion exposures to single chemicals and/or to mixtures including biological toxins and particles under flight conditions? | 4a2 | N | m | m | N | Y- | 2 | <u>×</u> | × | × | | | <u>×</u> | | | | - | - | - | | | | | |
| What are the effects of chronic exposultratine and larger (respirable and nearth, safety, and performance? | What are the effects ultrafine and larger particles on crew he performance? | What are the effects ultrafine and larger (particles on crew he performance? | What are the effects ultrafine and larger particles on crew he performance? | What are the effects of chronic exposure to utrafine and larger (respirable and nonrespirable) particles on crew health, safety, and performance? | 4 a6 | N | e e | N | е | α | - - | <u>×</u> | × | × | | | <u>×</u> | | | _ | - | ** | | vs. | | | | |
| 4 What is the effect of space flight on all microorganisms? | | What is the effect of microorganisms? | What is the effect of microorganisms? | space flight on all | 4b2 | 2 | - | 2 | 8 | 3 | 2 1 | <u>×</u> | × | × | × | × | × | | | | | | - | 9 | | | | |
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| | CB | What technology is available to identify microorganisms in crew and environmental (air, water, surfaces) specimens. How are microorganisms controlled by anti-microbial procedures? | What, if any, are the interactions between the effects of microgravity on crewmembers and the effects of off-baseline levels of atmospheric parameters, including gas composition, pressure, and temperature? | What are the effects of all potential atmospheric components, including contaminants and factors on physical and psychological well-being and crew performance? | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | How is the effect of gravity (and microgravity) on cells influenced by magnetic fields and radiation? | Can crop plants produce sufficient edible biomass extra-terrestrially to support human crews? The following constraints should be considered in | studying this question: — Closed environments | Recycling Limited space | Gravity effects Phytogenic volatile compounds and other trace | contaminants | Adventitious biota (microbial and other) |
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| |) Ue | ons and the following the foll | d eff | pote od : (aq orate orate ultur |
| | | at conditions are required to optimize the erating and water recycling capacity of ots? The following factors represent the imum that should be considered in studyingtion: Light quantity, quality, periodicity, gas position and density. Root environment: substrate, nutrients, ume, temperature, etc. Aerial environment: gas composition and serue, temperature, planting density, etc. | an the | at is the potential for using the following mative food sources in a CELSS? Animals (aquatic and terrestrial, vertebrate invertebrate) Algae -ungi Bacteria Non-traditional higher plants Tissue-cultured cells Synthetics |
| | cal | con atin ium ion: ight ositi oosti loot he, | are obia S? | hat is the ernative for Animals dinverte Agae Furgi Non-trac Tissue-C Synthetia |
| | riti | What conditions are required to optimize the food generating and water recycling capacity of crop plants? The following factors represent the minimum that should be considered in studying th question: — Light quantity, quality, periodicity, gas composition and density — Root environment: substrate, nutrients, volume, temperature, etc. — Aerial environment: gas composition and pressure, temperature, planting density, etc. | What are the effects of adventitious biota (microbial and other) over long periods in a CELSS? | What is the potential for using the following alternative food sources in a CELSS? — Animals (aquatic and terrestrial, vertebh and invertebrate) — Agae — Fungi — Bacteria — Non-traditional higher plants — Tissue-cultured cells — Synthetics |
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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|---|---|---|---|---|----|---------|----------|----------|---------|---|---|----------|-----|---|---|---|----|----|--------------|--------------|---|--------------|------|--------------------|----------------|----------|
| What are the specific nutritional requirements for 9b8 humans in space? This question should consider at least the following: — Caloric requirements — Will the nutritional requirements of the crew change and require modified diets over time of flight — Fluid requirements — Distribution of the macro nutrients (protein, carbohydrate, lipid) — Flher and micronutrient requirements | What are the specific nutritional requirements for humans in space? This question should consider at least the following: — Caloric requirements _ Will the nutritional requirements of the crew change and require modified diets over time of flight — Fluid requirements — Distribution of the macro nutrients (protein, carbohydrate, lipid) — Fiher and micronutrient requirements | are the specific nutritional requirements for this in space? This question should consider at the following: saloric requirements iil the nutritional requirements of the crew ge and require modified diets over time of luid requirements bistribution of the macro nutrients (protein, hydrate, lipid) | are the specific nutritional requirements for this in space? This question should consider at the following: saloric requirements iil the nutritional requirements of the crew ge and require modified diets over time of luid requirements bistribution of the macro nutrients (protein, hydrate, lipid) | are the specific nutritional requirements for this in space? This question should consider at the following: saloric requirements iil the nutritional requirements of the crew ge and require modified diets over time of luid requirements bistribution of the macro nutrients (protein, hydrate, lipid) | œ | Ν | <u> </u> | E | <u></u> | N | + | <u>×</u> | × | × | | | × | | | - | - | - | 3,4, | t, 5, | 6,7,9,10 | 9,10 |
| What are the acceptability criteria for foods and in what priority order should they be evaluated? Some criteria include: - Safety and freedom from toxic substances and infectious agents - How will the crew respond to diet on a Mars mission - Nutrient and attribute balance - Familiarity/cultural experience - Taste/texture/color/shape - Flexibility in preparation methods - Cooking (time, complexity, etc.) - Seasoning (diversity of options) - Compatibility with other menu items - Variety What food groups fulfill these requirements? - How can the biomass candidates be used or modified to arthe biomass candidates be used or | What are the acceptability criteria for foods and in what priority order should they be evaluated? Some criteria include: - Safety and freedom from toxic substances and infectious agents - How will the crew respond to diet on a Mars mission - Nutrient and attribute balance - Familiarity/cultural experience - Taste/texture/color/shape - Flexibility in preparation methods - Cooking (time, complexity, etc.) - Seasoning (diversity of options) - Compatibility with other menu items - Variety What food groups fulfill these requirements? - How can the biomass candidates be used or modified to achieve the desired requirements? | ت کو ی | ت کو ی | ت کو ی | | N | α | <u>£</u> | ~ | N | - | × | _× | × | | | × | | - | - | - | - | ri . | ← σ• | 0 | |
| How do the above nutritional questions apply to CELSS produced foods, used either as a nearly complete diet or as a supplement to stored food? | Ċ. | Ċ. | Ċ | Ċ | 65 | N | Ν | 2 | _ | ~ | | <u>×</u> | | × | | | | | | - | | - | က် | 9, 10 | | |

Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| <u> </u> | 2 03 | 2 | 100 | C1 C2 C3 C4 C5 Critical Question | Quest# | Cr1 | 2 | ဨ | 4 | 2 | 9 | 7 | 8 | 6 | 9 | = | 12 | 131 | 4 | 15 | 16 | 17 | 18 | Gro | Group w/ other | £ | ä | Disc |
| + | | 4 | | To what extent will micro-organisms used in a | 9c21 | 2 | 2 | 8 | 7 | 8 | _ | × | × | × | | | × | | | <u> </u> | 8 | _ | _ | 3, 6 | | | | |
| | | | | physico-chemical waste processor present an | | - | | | | | | | | | | | | | | | | - | | | | | | |
| | | | | Issue of performance degradation? | | | | | | | | | ; | _; | | | | | | | _ | | | | | | | - |
| - | | | | What are the best technologies for recycling the | 9c245 | 2 | 9 | _ | N | _ | - | × | × | <u>×</u> _ | | | × | | | <u>-</u> | 2 | | _ | ω, O | | | | |
| | | | | water required for a Mars mission to acceptable potable and hygiene levels? | | | | | | | | | | | | | | | | | | | • | | | | | |
| · | | 4 | | What are the storage requirements for potable and | 9c27 | 2 | 9 | _ | N | N | _ | × | ⊞ | × | | | × | | | _ | 0 | _ | _ | 3, 6 | | | | |
| | | | | hygiene water in a CELSS? Consider: | | | | | | | _ | | | | | | | | | | | | | | | | | |
| | | | | — Safety/redundancy | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | Control of microbial film on surfaces | | | | | | | _ | | | | | | | | | | | | | | | | | |
| | | | | — Volume | | | | | | | | | | | | | | | | | | | | | | | | |
| <u>:</u> | | 4 | | What will be the acceptability thresholds for | 9c28 | 2 | <u>ო</u> | _ | 8 | α. | _ | × | | × | | | × | | | _ | _ | _ | _ | э, б | | | | |
| | - | | | revitalized air in an operational CELSS? | | | | | | | | | | | | | | | | | | | | | | | | |
| • | | 4 | | What currently available air treatment | 9c29 | 2 | <u>ო</u> | _ | 8 | N | _ | × | × | × | | | × | | | _ | _ | _ | _ | 3, 6 | | | | |
| | | | | technologies can be adapted to a CELSS use, and | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | what technologies will need to be developed for | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | space application? | | | | | | | | | | | | | | | | | | | | | ١ | | ١ | ٦ |

Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| what strategies or techniques exist for monitoring gld31 2 2 1 1 1 2 2 1 1 X X X X X X X X X X | 5 | S | ខ | ঠ | છ | | - | | 2 | 3 | 4 | | | | | | Ψ- | 느 | ᄕ | 드 | 上 | 드 | 1 | 上二 | _ | Ĭ | ° | Disc |
| and control of the known or suspected possible curese of life support system instability? Consider: - Pests or pathogens (disease) - SMACS - Toxicants produced by humans, by processing procedures, or by the plants themselves - Minorganic statements in environmental controls - Minorganic experiments for CELSS system - Minorganic experiments for CELSS system - Failure of microbial cultures in agal - Failure of microbial cultures in agal - Failure of microbial cultures afte and reliable operation? Address the requirements for CELSS system - Subsystem redundancy - System modelling and behavior - Allenments stategles for system monitoring and control - Allenments extraegles for system monitoring and control - Allenments operation subsystem - Subsystem experiments within a limited of conditions and intense dynamics, subject to unknown or conditions and intense dynamics, subject to unknown or characterized instabilities, such as some characterized instabilities, such as | * - | | | 4 | | What strategies or techniques exist for monitoring | | | + | <u> </u> | ~ | ٦ | † ^ | 1 | 1 | + | + | ` | | ┸ | ┵ | 2 ل | ┵ | ↓ † | _ | " | 4 | |
| Considers of life support system instability? Pests or pathogens (disease) - SMACS - Toxicants produced by humans, by processing procedures, or by the plants themselves - Amosphere leakage - Perturbations in environmental controls - Microgravity - Unanticipated ecological interactions - Schadulad or unschaduled system or mission - What are the requirements for CELSS system events - Failure of microbial cultures in algal termentation systems - Food variety - Subsystem redundancy - Interaction with Chemical - Physical - System modeling and behavior - Alternative strategies for system monitoring - Ealure of a subsystem - Alternative strategies for system monitoring - Failure of a subsystem - Alternative strategies for system monitoring - Failure of a subsystem - Alternative strategies for system monitoring - Failure of a subsystem - Alternative strategies for system monitoring - Failure of a subsystem - Alternative strategies for system monitoring - Failure and intense dynamics, subject to unknown or poorly characterized instabilities, such as | | | | | | and control of the known or suspected possible | | | | | | | <u>. </u> | | | _ | | < | | | | ų . | | | | | oʻ | |
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Table 7 Pa

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

Table 7

| Lestion Quest# Cr 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 18 Group w/ other Disc | mal) 9d34 2 2 2 1 2 | afety and reliability (maximal), and extended in an integrated, controlled | nematical models be utilized to aid in 9d35 2 3 3 1 2 2 1 X X X 1 1 2 1 1 3, 8, 11 3, 8, 11 3, 8, 11 3, 8, 11 | a 9d38 2 3 4 2 2 2 1 X X X 1 2 1 1 | dry 9e39 2 2 2 1 2 1 1 X X X X X 1 2 1 1 10, | norphology and reproductive capability 9e40 2 2 2 1 1 1 X X X X X X X X X X X X X X | 9641 2 2 2 1 2 1 1 X X X X X X 1 1 2 1 1 2 1 1 2 1 1 1 1 | 9843 2 1 NR 1 2 2 1 X X X X X 1 2 1 1 10, | sufficient supplies of food be provided 9f1c 2 2 1 1 X X X X X X X X X X X 1 1 1 1 1 | monitor 9f5a 2 3 3 2 2 1 1 X X X X X X 1 1 3, | potential biomarkers for assessing 4a5 3 2 3 3 2 1 X X X X X 1 1 1 4 8 |
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| C #1 | 4 What are the thresholds of system size (minimal) 9d34 2 2 | and system safety and reliability (maximal), can these be extended in an integrated, contrasystem? | mathematical models be utilized to aid in 9d35 2 3 esign, system simulation, and system | s are required for automation of a 9d38 2 | 9839 | fuctive capability 9e40 2 15% and 38% election criteria | sures can be utilized if 9e41 2 production is significantly | | provided 9f1c 2 and ission? | nitor 9f5a 2 | က |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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| | Question | and pig | ecui ¥ fi | Improve nutrient quality and bioavailability Reduce natural toxicants Optimize plant architecture | n edible foods and/or ingredients be derived in non-edible plant wastes? What are the crop plant-specific limits of this bability? | pro tab | iy a echi nd v spa | proc of the | Ispii vate r tre ish lon i |
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| | į | What robotic and automated procedures should I developed for planting, growing, and harvesting crop plants? | How can molecular genetic technology, including germplasm screening, be used to develop crop cultivars better fit for CELSS use in space? (for example) | = 2 0 0 | Can edible foods and/or ingredients be derived from non-edible plant wastes? — What are the crop plant-specific limits of th capability? | What are the processing requirements necessary to convert metabolic wastes into nutrients suitable for plant growth? | What currently available waste treatment/nutrie regeneration technologies can be adapted to a CELSS use, and what technologies will need to be developed for space application? (Note question 16.8) | What are the production rates and chemical compositions of the different waste streams that are to be processed in a CELSS? | Can plant transpiration water qualify as potable and hygiene water? If not, what currently available water treatment technologies can be adapted to polish transpiration water in a CELSS and what technologies will need to be developed space application? |
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | | | | the production rate demands for potable and hydiene water, then what types and numbers of | | | | | | | | | | | | | | | | | | | | |
| | | | | plants will be required, and what environmental | | | | | | | | | | | | | | | | | | | | |
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| | | 4 | | what currently available water increments technologies can be adapted to recycling the | | | | | | | | | | | | | | | | | | | | |
| | | | | various grades of water (hygiene, wash, etc.) in a | | | _ | | | | | | | | | | | | | | | | | - |
| | | | | CELSS and what technologies will need to be | | | | | | | | _ | _ | | | | _ | | | | | | | |
| | | | | developed for space application? | | | _ | | | , | | | | | > | | | ٠ ، | | _= | 3.6 | | | |
| | | 7 | | What types and surface area of plants will be | 9c30 3 | 8 | <u>£</u> | - 2 | 2 | | <u>`</u> ×_ | <u>`</u> | <u>< </u> | | < | | | 1 | | | | | | |
| | | <u> </u> | | required to meet the production rate demands for | | | _ | | | | | | | | | | | | | | | | | |
| | | | | revitalized air and what environmental conditions | _ | | _ | _ | | | | | | | | _ | _ | | | | | | | |
| | | | | do these plants require? | | | | | | | | | | | > | | | - | _ | _ | α (*) | ÷ | | |
| | | 4 | | What robotic and automated procedures should be | 9437 3 | <u>-</u> | _ | <u>က</u> | 2 | _ | × | _ | × | | <_ | | | | _ | | | | | |
| | | | | developed for control, monitoring, and operations? | | | | | | | | | ; | | | | | | | • | 9 | 1 | | _ |
| | | 4 | | Can proposed food processing techniques be | 9644 3 | 2 | - | 1 | 21 | | <u> </u> | <u>`</u> < | < | | <u><</u> | | | 1 | | | _ | | | |
| | | | | modified to work effectively at reduced gravity? | | _ | | | | | | | | | <u> </u> | | | - | | | 9 | | | |
| | m | | | Can wastes be successfully disposed of on a Mars | 9f3a 3 | ~ | 80 | 2 | - | _ | × | | × | | <u><_</u> | | _ | | <u>-</u> | | | | | |
| | | | , | mission without impacting planetary protection? | _ | | | | | | ; | | ; | | <u> </u> | | | - | | _ | 9 | | | |
| | ٣. | | | Do regenerative systems exist to provide safe and | 914c | <u>ო</u> | က | 2 | - | | <u>×</u> | | ×_ | | <u><</u> | | | | | | | | | |
| | | | | sufficient supplies of food for the Mars mission? | | | | | | | _; | | ; | | <u> </u> | | | 7 | | | 3 | | | |
| | C. | | | Do automated systems exist to monitor food | 9151 | က — | _ | 2 | 2 | _ | × | | × | | <u> </u> | | | | | | | | | |
| | | | | safety/quality for Mars mission? | | | | | | _ • | > | | | | <u> </u> | × | | 7 | | _ | | | | |
| | <u></u> | 4 | | ing the cou | 10 2 | 3 8 | _ | | د | <u> </u> | Χ_ | | < | <u> </u> | | <u> </u> | | | | | | | | |
| |) | | | robotic and human exploration to protect the Earth | | | | _ | | | | | | _ | | | | | _ | | | | | |
| | | | _ | from harm caused by the importation of biological | | | | | | | | | | - | | | | | | | _ | | | |
| | | | | materials from Mars (back contamination)? | | | | | | | > | > | > | > | _ <u>×</u> | | | <u> </u> | - | | ω, 4 | 4, 5, 6, | 7 | |
| N | <u>ආ</u> | 4 | | How does prolonged space flight affect behavior and groun dynamics (including species, sex, and | 1a9 | - | Ν | n | ง | <u> </u> | < | <u> </u> | | | <u> </u> | | | | | | | | | |
| | | | | age differences)? | | - | _ | | \dashv | \dashv | 4 | | | ┪ | \dashv | 4 | | 1 | 1 | 4 | 4 | | | |
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Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

Table

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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Table 7 Critical Questions That Would Utilize A Lunar Base Lable 7 Listed by Category and Criticality

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| | | anical activity regulating protein and structure and | ted by both ents? How can | yrate | tal models of | dol | 1 | on the muscular | atrix? | course of bone | rent areas of | gravity or | le time course | ith changes in | s at the same | ocirculation? 10 | ors? | ocesses are | and connective | interact with | ocesses affected | | of mass, ultra- | tion, and | extent do irreversible | affect structural |
| | Critical Question | What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and | function of muscle, as investigated by both ground-based and flight experiments? How | this information be used to integrate | neuromuscluar and musculoskeletal models of | mechanics and adaptation to develop | countermeasure protocols? | What are the effects of unloading on the muscul | intracellular and extracellular matrix? | What are the rate, extent, and time course of b | and connective tissue loss for different areas | the body during exposure to microgravity or | simulated microgravity? How is th | of regional tissue loss correlated with changes in | the tissue stress and strain historie | site? To changes in regional microcirculation? | other regional and systemic factors? | Which endocrine and nutritional processes are | required for maintenance of bone and connective | tissue? How do these processes interact with | mechanical loading? Are these processes affe | by space-flight? | Is bone loss reversible in terms of mass, ultra- | and micro-structural organization, and | microstructure? To what extent do irreversible | architectural adaptations |
| | | What is the link between mech (stress) and hormonal state in turnover and gene expression 8 | function of muscle, as investigating and flight experim | this information be used to integ | neuromuschar and musculoskele | mechanics and adaptation to deve | countermeasure protocols? | | intracellular and extracellular ma | | | the body during exposure to micro | simulated microgravity? How is th | of regional tissue loss correlated w | the tissue stress and strain historie | site? To changes in regional micr | other regional and systemic fact | | | tissue? How do these processes | mechanical loading? Are these pr | by space-flight? | | | microstructure? To what | architectural adaptations |
| | | 4 What is the link between mech (stress) and hormonal state in turnover and gene expression (| function of muscle, as investigat | this information be used to integ | neuromuscluar and musculoskele | mechanics and adaptation to deve | countermeasure protocols? | 4 What are the effects of unloading of | intracellular and extracellular ma | 4 | | the body during exposure to micro | simulated microgravity? How is th | of regional tissue loss correlated w | the tissue stress and strain historie | site? To changes in regional micr | other regional and systemic fact | 4 | | tissue? How do these processes | mechanical loading? Are these pr | by space-flight? | 3 4 Is bone loss reversible in terms | | microstructure? To what | architectural adaptations affect structural |
| | C1 C2 C3 C4 C5 Critical Question | | function of muscle, as investigation of muscle, as investigation ground-based and flight experim | this information be used to integ | neuromuscluar and musculoskele | mechanics and adaptation to deve | countermeasure protocols? | | | | | the body during exposure to micro | simulated microgravity? How is th | of regional tissue loss correlated w | the tissue stress and strain historie | site? To changes in regional micr | other regional and systemic fact | | | tissue? How do these processes | mechanical loading? Are these pr | by space-flight? | 4 | | microstructure? To what | architectural adaptations |

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | . 2 | | 4 | | How does mechanical stress and change in | | | 1 | 1 | + | 十 | 寸 | 7 | <u> </u> | ₂ | 일 | | 12 | 13 | 4 | 5 | 9 | 7 | 8 | Group | / ₩ 0 | other | r Disc | ပ |
| | _ | | | | contribute to bone and connective tissue | 200 | 2 | 7 | 7 | | - | <u>ო</u> | <u>×</u> | × | × | × | × | × | | _ | | - | - | - | | | | | Т |
| | | | | | formation? Are stress and/or changes in stress required for continued structural integrations | | | | | | <u>-</u> . | | · · · · · · · · · · · · · · · · · · · | | | | | | | | | | | | | | | | |
| | 2 | | 4 | | What are the patterns of in-vivo mechanical | 74 | c | C | | | | | | | | | | | | | | | | | | | | | |
| | | | | | loading (e.g., tissue strain, stress, strain rate, | 3 | ų | 2 | າ | | <u>-</u> | <u> </u> | <u>×</u> _ | <u>×</u> _ | × | × | | × | | 21 | _ | _ | | က် | . 7, | ۵ | | | |
| | | | _ | _ | stress rate)in normal and low-g environments? | | | | | _ | _ | | | | | | | | | _ | | | | _ | | | | | , |
| | N. | | 4 | | What are the bone and connective tissue markers | 5d3 | 0 | ~ | ď | <u>,</u> | - | | | > | | - | | ; | | | | | | | | | | | |
| _ | | | | | of metabolism (protein synthesis, secretion, and | | _ | | | | - | <u> </u> | <u><_</u> | <u><</u> | < | × | | × | _ | 7 | _ | = | _ | er e | 7, | œ | | | |
| | | | | | degradation)? How can bone marker data be used | | | | | 1 | | | | | | | * | | | _ | | | | | | | | | |
| _ | | | | | to investigate and predict regional changes in bone metabolism? | | | | | | | | | | | | | | | | | | | | | | | | |
| <u> </u> | 2 | | | | What key elements of bone and connecting the | 9 | | | | | | · | | | | | | _ | | | | _ | | | | | | | |
| | | | | | structural assembly impact the highestructure | 999 | 2 | es es | ~ | - | <u>-</u> | ო | × | × | × | × | | × | | _ | | | _ | _ | | | | | |
| | | | | | properties? | | | | | | | | | | | | | | | - | | | | | | | | | |
| •• | 2 | | | | Are there specific load histories that affect the | 17 | | | | _ | | | | | | | _ | — | _ | | | | | | | | | | |
| | | | | | macromolecular assembly of connective tissues? | `nc | N. | N | <u></u> | - - | _ | ო | × | × | × | × | ^ × | × | | _ | | - | | 7 | | | | | |
| . 4 | 2 * | | 4 | | What are sensory inputs and coordination of | Gho : | , | <u>`</u> | | | | | | | _ | | | | | _ | | | | | | | | | |
| | _ | _ | | _ | muscular outcomes organized for generation of | | | | <u> </u> | <u>-</u> | Ξ | N_ | × | × | × | × | × × | _ | | - | _ | _ | _ | 7, | ω | | | | |
| | | | | | posture and locomotion before, during, and after | | | | | | | | | | | | | | _ | | | | | | | | | | |
| - 7 | 2 . | | | | | | | | | - | | | | | | | _ | | | | | | | | | | | | |
| | _ | | | | readaptation to partial of 1 and 1 a | 663 | 2 | 2 | _ | ~ | 7 | N | × | × | × | × | <u>×</u> | _ | | _ | _ | | | | c | | | | |
| | | | | | microgravity? | _ | | | _ | | | | | | | | | | | | | | | <u>:</u> | ю | | | | |
| 7 | • | 4 | | | What adaptive processes modify motor control | | | | | _ | | _ | | | | | | | | | | | | | | | | | |
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| | | | | <u> </u> | of motor responses in altered states of gravity? | | - | _ | | _ | | | | | | | | | | | | | _ | | | | | | |
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| 4 | \dashv | \dashv | \dashv | ۲ | Joint and body position in microgravity? | - | _ | _ | | _ | | _ | : | | _ | _ | | _ | _ | | | | | <u>.</u> | დ ო | | | | |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Table 7 C

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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | | | 10.5 | Calcal Question | Quest# | Ü | - | က | 4 | 2 | 6 7 | 8 | 6 | 듸 | 5 | 12 | - 3 | 4 | - | - | <u> </u> | | d | Group w/ ourer | | 2 |
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| | | | _ | countermeasure (physiological system | | _ | | | _ | | _ | | | _ | | _ | | | | | | | | | | |
| | | _ | | maintenance), will going from 1-g to microgravity | | | | | | | | | | | _ | | | | | | _ | | | | | |
| | | | | cause repeated maladaptions? | | | _ | | | | | | | | _ | _; | | | | <u> </u> | | d | | | | _ |
| ٥. | | 4 | | What are the joint effects of radiation and | 811113 | 7 | - | - | _ | 7 | ი _ | ^- × | <u>×</u> × | <u>×</u> | <u> </u> | <u><</u> | | | | | |) | | | | |
| | | | _ | microgravity? | | | | | | | _ | | _ | | | | | _ | | | _ | | | | | |
| | | , | | How do neoplasms common to chronological | | | | | | | | _ | | | | | | | _ | | | _ | | | | |
| | | | | aging relate to limitation of cell lifespan and | | | _ | _ | | | | | _ | | | | | _ | _ | | | _ | | | | |
| | | | | susceptibility to abnormal growth regulation under | | | | _ | | | | | | _ | -; | | | | | | | | | | | |
| | | | | altered gravitational fields? | | | | | | | | | | | | ; | | | | | | | • | | | |
| Ċ | * | | | What is the role of gravity in the regulation of the | 8Vb2 | 2 | 2 | 2 | 7 | 7 | က | `` × | ≏ × | <u>×</u> × | <u>×</u> | <u>×</u> | | | <u> </u> | | | <u>†</u> | | | | |
| 4 |) | | | distribution composition and pressure of | | | _ | | | | | | | _ | | | | | | | | | | | | |
| | | | | tar/fluida in living exetence from cells to | | | | | | | | | | | _ | | | | | _ | | _ | | | | |
| | | <u>:</u> | | water/fiulds in living systems from cens to | | | | | | | | | _ | | | | | | | | _ | _ | | | | _ |
| | | | | complex organisms? How do these changes | | | | | _ | | | | | | _ | | | | | _ | _ | | | | | |
| | | | | influence other homeostatic and regulatory | | | _ | | | | | | | | | | | | | _ | | _ | | | | |
| | | | | mechanisms? | | | | | _ | | | _ | _ | | _ | | | | | <u> </u> | | ٠ | 7 | ~ | | |
| _ | | | | le misculeskeletal growth development, and | 8V11 | 7 | <u>.</u> | _ | _ | က | - | × | `` × | <u>×</u> × | <u>×</u> | <u>×</u> | | | <u>-</u> - | <u> </u> | | <u> </u> | | | | |
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| | _ | | - | function compromised duling spacelinging and daily | | | | | | | , | | | | | _ | | | | | _ | _ | | | | |
| _ | _ | _ | _ | they readapt upon return to Earth? The structure | | | | | | | | | | _ | | | | | | | _ | _ | | | | |
| | | | | and functional systems that should be examined | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | | carefully are: (1) the postural muscles, (2) muscle | | | | | | | | | | | _ | | | | | | | _ | | | | |
| | | | | spindles, (3) weight/load-bearing bones and joints, | | | | | | _ | | | | _ | _ | | | | | | _ | | | | | |
| | | | | (4) intervertebral discs, (5) the architecture of | | | | | | | | | | | | | | | | | | _ | | | | |
| | | _ | | the connective tissues of the body and (6) | | | | | | | | | | _ | | | | | | | | _ | | | | |
| | | | | musculoskeletal innervation. | | | | _ | | | | | | | | | | | • | <u> </u> | _ <u>-</u> - | - | α | | | |
| - | * | | | What is the role of fluid redistribution in the | 8V14 | N | 7 | 2 2 | <u>7</u> | N | ო | × | × | × | <u>×_</u> × | <u><</u> | | | - | | | | | | | |
| <u> </u> | _ | | | response of the musculoskeletal system to altered | | | | _ | | | | | | | | _ | | _ | | | | | | | | |
| | | | | gravity and how does gravity impact the | | _ | | | | | | | | | - | | | _ | | | | | | | | |
| | | | | homeostasis of fluid compartments within tissues? | | | | | | | | | | | | | | | | - | <u> </u> | <u></u> | er. | œ | | |
| 2 | * | - | | What signals the musculoskeletal adaptation to | 8/19 | 7 | - | - | - - | CJ. | <u>m</u> | × | <u> </u> | <u>-</u> - | <u> </u> | <u>< </u> | | | | | | _ | 5 |) | | |
| | | | | spaceflight? Are the signals the same as those | | _ | | | | _ | | | | | _ | | | | | | | | | | | |
| | | | | found in biomechanical unloading on Earth? | | 4 | | 1 | \dashv | 4 | 4 | _ | | 1 | 1 | ┨ | ┨ | 4 |] |] | 1 | 1 | | | | |

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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

Table 7

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| | | | | | requirements for telecommunications to optimize crew performance? | | | | | | | | | | | | | , | | <u>`</u> | | | | | |
| | , | | | | What are the most effective schedules for work, | 1f2 3 | က | <u>۳</u> | ~ | _ | 2 | × | <u>×</u> _ | × | | | | | | <u>-</u> - | <u>+</u> | | | | |
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| | | | | | during long-duration exposure to space? | | | | | | | ; | | ; | | > | | Ţ | - | <u> </u> | | | | | |
| | \$ | | | | How is workload optimized for various space | 116 | 0 | - | <u>-</u> _ | 7 | | <u> </u> | < | <u> </u> | | < | _ | | | | | | | | |
| | | | | | explorations? | | | | | , | | | | | | > | | | - | ÷ | - 2 | _ | | | |
| | ċ | | | | What minimally intrusive hardware and software | 1110 3 | _ | - | 2 | | | <u> </u> | < | <u> </u> | | < | _ | | | | <u>'-</u> | | | | |
| | <u> </u> | | | | capabilities are best suited for obtaining | | | | | | | | | _ | | | | | | _ | | | | | |
| | | | | | performance data in flight? | _ | | | | | | - 7 | | ; | | | _ | _ | ٥ | <u> </u> | | 4 | | | |
| | 9 | | | | What methods characterize the process of | 192 | _ | <u>د</u> | 3 | _ | _ | ×_ | | ×_ | _ | < | | | <u>. </u> | - | | | | | |
| | 1 | | | | individual and team adaptation to stressors (e.g. | | | | | | | | | | | _ | | | | | | | | | |
| | | | | | isolation, confinement, and risk) inherent in space | | | | | , | | | | | | | | | | | | | | | |
| | | | | _ | flight? | | | | _ | | | > | | > | | <u> </u> | - | | | | <u> </u> | _ | | | |
| | 2 • | | | | What are effective protocols for sustaining crews | 195 3 | 2 | Ξ | 2 E | <u></u> | <u>n</u> | <u><_</u> | | < | | <u> </u> | | | | | _ | | | | |
| | | | | _ | in case of loss of a crew member inflight, or loss | | | | | | | _ | | | _ | | | | | | | | | | |
| | | _ | | | of a family member or friend on earth? | | | | | | _ | ; | > | > | | <u>></u> | | _ | - | | - | 3.4 | 5. 6. | 7 | |
| | ٥ | | 4 | | What are the effects of the space environment on | 2a1 3 | <u>ლ</u> | _ | - | <u> </u> | | <u><</u> | <u><</u> | <u><</u> | _ | < | _ | | | | _ | | | | |
| | | _ | | | sleep, sleep cycles, or the generation, expression | | | | | | | | | | | | _ | | | | | | | | |
| - | | | | | (period, phase, amplitude and/or waveform), and | | | | | | | | | | | | | | | | | | | | |
| _ | | _ | | _ | entrainment of metabolic, endocrine, reproductive, | | | | | | | | _ | | - | _ | | | | | | | | | |
| _ | | | | | and/or behavioral circadian rhythms? Of these | | | | | _ | | | | | | | | | | | | | | | |
| | | | | | effects, which result from altered gravity and | | | | | _ | | | | | | | | | | | | | | | |
| | | | | | which result from other environmental factors? | | \dashv | \Box | | \dashv | 4 | 4 | 4 | | 4 | 1 | $\frac{1}{2}$ | $\frac{1}{2}$ | - | | 1 | | | | |

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Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | | What are the effects of exercise on circadian rhythms and sleep? What pharmacological and nonpharmacological (e.g. light, exercise) agents can be used to reset the human biological clock? What are the effects of routine administration of pharmacological agents in space on circadian rhythms and sleep? | What roles do age and gender play? Is there a response of the circadian system to the space environment? | What are the mechanisms underlying the negative nitrogen balance and changes in lean body mass incurred during space flight? What are the pressible interventions, including dietary alterations in province. | Do the effects of space flight require added supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? | What is the time course and nature of body composition change due to space flight? Do changes in body composition (age and gender) have an effect on crew health and performance? | ectrolyte regulating |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | on anisms for the chronic adaptiv | white are the medianisms for the company shifts in fluid and electrolytes during space flight? How does the new steady state affect the body's ability to respond to heat stress, electrolyte | countermeasures? | What are the best methods to accurately measure | extracellular fluid, total body water, and | in space flight? | What are the effects of circadian rhythm change | in space flight on the responsiveness of the fluid and electrolyte system? | What are the roles of renal blood supply and renal | electrolyte handling in extracellular fluid volume | Latin happen the | What is the relationship between the cardiovascular adjustments to space flight and | those occurring in Earth-based models such as bedrest immersion, and head-down tilt? | Are the baroreflexes modified by space flight and | how do these affect orthostatic tolerance? Are | 6 | flight and how do these affect ormostatic | | How are countermeasures to adverse | cardiovascular effects of long- duration space | flight affected by changes in fluid distribution? | Are there appropriate animal and/or computer | models for studying each functional element of |
| - 1 | C2 C3 C4 C5 Critical Question | wilat are the med shifts in fluid and How does the new ability to respond | loading, EVA, and countermeasures? | What are the best | extracellular fluid, | interstitial volume in space flight? | What are the effec | in space flight on the rest and electrolyte system? | What are the roles | electrolyte handlin | Citolog of a city | cardiovascular adjustments to space | those occurring in | Are the baroreflex | how do these affe | chemoreflexes and | flight and how do | tolerance? | How are countern | cardiovascular eff | flight affected by | Are there appropr | models for studyir |
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Table 7

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| 5 | <u>ਨੂੰ</u> | g | 8 | C1 C2 C3 C4 C5 Critical Question | Quest# | 5 | Ë | 2 | 3 4 | - | ٣ | 1 | ļ | ٢ | Ļ | - | يا | Ŀ | Ľ | Ŀ | Ŀ | Ŀ | _ | ı | | |
| | 8 | ю | | Is pulmonary function altered in long-duration space flight at rest, exercise, or in a disease state? | | | 4 | | | | | <u> </u> |) × |) × | 2 × | - × | 2 | 4 | 0 - | ° – | | - 1 | | Group w/ | offic | Disc |
| | ام | ю 7 | 4 | What are the physiological similarities and differences of ground- based models of muscle atrophy and fiber transformation and | 5a4 | <u>., </u> | က | _ | | | ო | × | × | × | × | × | | | 8 | - | - | | က် | 7, 8 | | |
| 0 | * | 4 | 4 | weightlessness-induced muscle atrophy and fiber transformation? How valid are ground-based models for studying the characteristics of space-flight-induced muscle changes? What are the molecular signals and mechanisms that are responsible for the control of muscle hypertrophy and atrophy, and what are the | 561 | <u>ო</u> | <u>ო</u> | | - | | ო | × | × | × | × | × | | | 2 | | | _ | ෆ් | 7, 88 | | |
| | | | | specific stimuli that are generated by exercise or disuse to signal increased or decreased protein accumulation in muscle cells? | | | | | · | | | | | | | | | | | - | | | | | | |
| N | | 4 | | What is the molecular interrelationship between catabolic and synthetic rates of protein metabolism in unloaded muscles? | 5b2 3 | <u>ო</u> | <u>ო</u> | -8 | | | ო | × | × | × | × | × | | | 8 | - | - | - | ග් | 7, 8 | | |
| N | • | 4 | | What is the molecular basis for the effects of unloading on the susceptibility of muscle to injury or damage upon resuming normal weight-bearing states? | 567 3 | 8 | - 0 | -0 | | | က | × | × | × | × | × | | | N | _ | - | | 3, 7, | 60 | | |
| 8 | ග | 4 | <u> </u> | What are the similarities and differences of ground-based models and spaceflight-induced bone and connective tissue loss with respect to biomechanical, histomorphometric, biochemical, and hormonal changes? | 505 | ო | ო | - | | - | ო | × | × | × | × | × | | | | <u> </u> | | | 3, 7 | | | · · · · · · · · · · · · · · · · · · · |
| 7 | <u>е</u> | 4 | | What are histomorphological and architectural changes that occur in bone and connective tissue because of space-flight? | 5c7 3 | - 0 | N | ~ | - | | ю | × | × | × | × | × | | | - 1 | <u> </u> | | - | 3, 7, | ∞ | | |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | | | 4 | | Which endocuments to mechanical stresses? | | | | | | | | | | | | | | | | | | 1 | | | | |
| | 2 | | 4 | | Which specific models predict bone and connective | 545 | 3 | <u>α</u> | - | _ | ا | <u>×</u> | <u>×</u> | <u>×</u> _ | × | × | × | | | - | | | | | | | |
| | | | | | tissue structural transients during altered load | | | _ | | | | | | | | | | | _ | | | | _ | | | | |
| | | | | | environments? | | | | | | | | | | > | > | > | _ | | , | • | _ | 1 | Ç | | | • |
| | 2 | | 4 | | Is cytokine production and response to cytokine by | 5d10 | 3 | <u>~</u> | α_ | | <u> </u> | <u>×</u> ~ | <u>×</u> | Κ_ | <u><</u> | <u><</u> | <u> </u> | | <u> </u> | <u>-</u> | | | - | 2 | | | |
| | | | | | osteoblasts and osteoclasts affected by exposure | | | | | | | | | | | | | | | | | _ | | | | | |
| | | | | | to microgravity? | | - 1 | | | | | | | | | ; | _> | | | <u> </u> | | | | 5 | | | |
| | 2 | | 4 | | Are precursor cells of osteoblasts and osteoclasts | 5d11 | 3 | ~ | N | _ | <u> </u> | <u>×</u> m | <u>×</u> | <u>×</u> | <u>×</u> | × | × | | | <u>-</u> | | - | <u>:</u> | 2 | | | |
| | | | | | affected by microgravity? | | | | | | | | | | | _; | > | | | | T | | 7 | 5 | | | |
| _ | ċ | | 4 | | Do precursor bone cells respond to maturation | 5d12 | 3 | <u>-</u> | 2 | _ | | <u>×</u> ຕ | <u>×</u> ~ | <u>×</u> | <u>×</u> | <u>×</u> _ | <u> </u> | | | | <u> </u> | - | <u>:</u> | 2 | | | |
| | | | | | stimuli in a microgravity environment as they do | | _ | | | | | | | _ | | | | | | | | | | | | | |
| | | | | | on earth? | | | | | | | | | | : | | _; | | | | | | _ | Ç | | | |
| | Ċ | | 4 | | Do osteoblast require gravity to function | 5413 | 3 | - | N | _ | - | က | × × | <u>×</u> | <u>×</u> | × | × | | | <u>-</u> - | <u> </u> | - | _ | | | | |
| | 4 | | _ | | normally? If developed in microgravity will they | | | | | | | _ | | | | | | | | | | | | | | | |
| | | | | | function normally? | | | | | | | | | | | | - ; | | | | | | | α | 9 | | |
| | ٥ | ന | 4 | | Are there changes in the processing of signals | 6a1 | <u>ෆ</u> | 3 | 7 | _ | <u>-</u> | ^ | × × | <u>×</u> | <u>×</u> _ | <u>×</u> | Κ_ | | | _ | - - | | <u> </u> | ĵ | 2 | | |
| | 1 | | | | from the semicircular canals or otolith organs that | | | | _ | | | | _ | | | | | | | | | | | | | | |
| | | | | | occur with adaptation? Do these changes take | | | - | | | | | | | | | | | _ | | | | | | | | |
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| | | | | | structures or other related brainstem and cortical | | | | | | | | | | | | | | | _ | | | | | | | |
| _ | | | | | structures? What is the time course of such | | | - | | | | | | | | | | | | | - | _ | | | | | |
| _ | | _ | | _ | changes and do they correlate with space motion | | | | | | | | | | _ | | | | | | | | _ | | | | |
| | | | _ | | sickness? | | | | | | | | | | | | ; | | | | , | <u>-</u> - | <u> </u> | | 0 | | |
| | ċ | m | | | What are the neural (morphophysiological) and | 6a3 | n | - | N | Ξ_ | N | N N | <u>^</u> × | <u>×</u> × | <u>×</u> | <u>×</u> | <u>×</u> | | | | | - - | <u>-</u> | ř | 0 | | |
| _ | <u> </u> | | | | | | | | | | | | _ | | | _ | | | | | | | _ | | | | |
| _ | | | | _ | changes in neurotransmitters, neuroendocrine, or | | | | | | | | | | | | | | | | | _ | | | | | |
| | | | | | neurohumoral release can be correlated with space | | | - | _ | | | | | | | | | | | | _ | | _ | | | | |
| | _ | | | | motion sickness? | | | \dashv | _ | 4 | | | 7 | ㅓ | \dashv | 4 | 4 | _ | | | 1 | 7 | 4 | | | l | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | Question | in altered d coordination | it are the pharmacology, physiology, and output 6b4 ways that control the autonomic and endocrine uts characteristic of motion sickness? | s can best be used to | .⊑ | nd models are most as of angular and on, somatosensory orientation in a | 787 | 8Vb1 | position (fat and protein metabolism)? microgravity affect the function feeding behaviors of gastrointestinal | 8Vb10 |
| | Question | in altered d coordination | What are the pharmacology, physiology, and output 6b4 hathways that control the autonomic and endocrine utputs characteristic of motion sickness? | s can best be used to | .⊑ | nd models are most as of angular and on, somatosensory orientation in a | 787 | 8Vb1 | position (fat and protein metabolism)? microgravity affect the function feeding behaviors of gastrointestinal | 8Vb10 |
| | Question | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | logy, physiology, and output. e autonomic and endocrine if motion sickness? | What psychophysical correlates can best be used to 6c2a describe spatial orientation? | Does a change in vestibular input lead to changes in 6c3 visual and auditory localization and multisensory spatial orientation? | nost nd sory | 7g7 be | 8Vb1 | 9 8Vb4 | |
| | Question | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and output 6b4 pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | What psychophysical correlates can best be used to describe spatial orientation? | Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | nd models are most ns of angular and on, somatosensory orientation in a | 787 | 8Vb1 | position (fat and protein metabolism)? microgravity affect the function feeding behaviors of gastrointestinal | 8Vb10 |
| | Question | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and output pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | 4 What psychophysical correlates can best be used to describe spatial orientation? | 4 Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | nd models are most ns of angular and on, somatosensory orientation in a | interactions change in altered gravity? What pharmacological agents should be developed 7g7 | 8Vb1 | position (fat and protein metabolism)? microgravity affect the function feeding behaviors of gastrointestinal | 8Vb10 |
| | Question | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and output pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | What psychophysical correlates can best be used to describe spatial orientation? | Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional particles. | interactions change in altered gravity? S What pharmacological agents should be developed 7g7 | How does gravity affect the regulation of metabolism,? Basal metabolism, storage and substrate utilization? | Body composition (fat and protein metabolism)? How does microgravity affect the function including feeding behaviors of gastrointestinal function? | 4 How does gravity interact with other environmental factors to control regulatory physiology and behavior? |
| | 3 C4 C5 Critical Question | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What are the pharmacology, physiology, and output pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | 4 What psychophysical correlates can best be used to describe spatial orientation? | 4 Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? | What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional positions. | interactions change in altered gravity? What pharmacological agents should be developed 7g7 | How does gravity affect the regulation of metabolism,? Basal metabolic rate? Energy, metabolism, storage and substrate utilization? | position (fat and protein metabolism)? microgravity affect the function feeding behaviors of gastrointestinal | How does gravity interact with other environmental factors to control regulatory physiology and behavior? |

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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

| C1 C2 C3 C4 C5 Critical Question What are the transduction mechanisms that couple BV17 3 7 7 7 X X X X mechanical stress to musculoskeletal mass and strength? What are the activation and force development processes of muscle and bone cells? Do we need artificial gravity countermeasures to protect from physiological deconditioning of a mission to Mars? How should artificial gravity be applied in terms of 12 2 3 3 3 2 1 1 1 X X X X gload, rotation rate, and intermittent versus continuous exposure? What models can developed to describe the effects of intermittent and variable graze. What are the effects of intermittent and variable graze 4 3 2 3 2 1 1 X X X X gravity fields on circadian rhythms, and how does this affect the use of artificial gravity as a countermeasure to microgravity? What are the effects of intermittent and variable graze 4 2 1 1 2 2 1 X X X studying the effects of non-gravity-related by sudding the effects of non-gravity-related physical-chemical and psychological space-fight-induced stressors on circadian rhythms and sleep? What are the effects of cyteme environments on human circadian rhythms? What are the effects of non-gravity-related physical-chemical and psychological space-fight-induced stressors on circadian rhythms and sleep? What are the effects of cophalad fluid shifts on 2a12 4 3 2 2 1 3 X X X X X S suddying the effects of cophalad fluid shifts on 2a2 2 3 3 2 1 3 X X X X X S S S S S S S S S S S S S S | | 10 11 12 13 14 15 16 17 18 Group W/ | X X 1 1 1 1 3, 7, 8 | X X X 1 2 1 1 2, 3, 6 | X X 1 2 1 1 2, 3, 6 | X | X X X 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | X 1 2 1 1 3, 4, 5 | X X 1 1 3 4, 5, | X X |
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| the transduction mechanisms that couple 8VI7 3 ? ? ? ? ? ? ? ? | | | | | ***** | × | | × | | |
| Question Quest# Cr 1 2 3 7 7 7 al stress to musculoskeletal mass and What are the activation and force ent processes of muscle and bone cells? 12 1 1 2 1 end artificial gravity countermeasures to om physiological deconditioning of a on Mars? 12 1 1 2 1 uld artificial gravity be applied in terms of variable of the effects and intermittent versus 12 3 3 3 2 1 dels can developed to describe the effects of intermittent and variable stressers on mission nnce? 113 4 3 NR 2 2 in the effects of intermittent and variable slds on circadian rhythms? 2a2 4 3 2 3 2 the use of artificial gravity? the appropriate ground-based analogs for the effects of extreme environments on irreadian rhythms? 2a9 4 2 1 1 the effects of ortreme environments and psychological chemical and psychological and sleep? 3 3 2 the effects of cephalad fluid shifts on the effects of cephalad fluid shifts on the effects of cephalad fluid shifts on the effects of cephalaga fluid shifts on the effects of cephalaga fluid shifts on the effects of cephalaga fluid shifts on the effects of cephalaga fluid shifts on the effects of cephalaga fluid | • | | | × - | | | | | | |
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| Question the transduction mechanisms that couple al stress to musculoskeletal mass and What are the activation and force ent processes of muscle and bone cells? eed artificial gravity countermeasures to om physiological deconditioning of a o Mars? uld artificial gravity be applied in terms of otation rate, and intermittent versus is exposure? dels can developed to describe the effects nental behavioral stressers on mission nnce? the effects of intermittent and variable elds on circadian rhythms, and how does at the use of artificial gravity? the appropriate ground-based analogs for the effects of extreme environments on ircadian rhythms? the effects of non-gravity-related chemical and psychological and sleep? | | C | ო | | ო | | 4 | 4 | 4 | 4 |
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Critical Questions That Would Utilize A Lunar Listed by Category and Criticality

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| į | | What are the relationships between the stressors associated with space flight; the source, duration and magnitude of the stressor; and decreased immune function? — Are there effective operational procedures or countermeasures to counteract the stressors or their effects? | | Are there appropriate animal and/or computer models for studying each functional element of pulmonary adjustments to microgravity? What is the relationship, if any, between the pulmonary adjustments to space flight and those occurring in Earth-based models such as bedrest, immersion, and head-down titt? | onse | What are the circuitry and signals in the vestibular nuclei and brainstem that generate a gravito-inertial frame of reference? What are the roles of the different regions of the cerebellum? | ଅ | al ntral |
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Page 27

Table 7 Critical Questions That Would Utilize A Lunar Base Lusted by Category and Criticality

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| δ α α α α α α α α α α α α α α α α α α α | | What models of sensory-motor transformation be used to predict motor behavior best in altere gravitational states? | How are the following cell functions influenced by gravity and/or affected by microgravity: the expression and regulation of genetic information; cell division; cell differentiation; signal transduction, including signal-membrane interactions, and signal-effector linkage; membrane dynamics; intracellular transport; secretion; alternate pathway regulation; and cell-to-cell communication? The importance of selecting cells and cell lines that can provide interpretable results bearing on precise questions cannot be overemphasized. | How long can single cells cope with changes in gravitational force without adverse results? Do these effects persist after return to unit gravity? | What structural and morphometric alterations will occur in the extracellular matrix, the connective tissue, and the musculoskeletal systems in long term spaceflight? How will this result in altered differentiation of cells, and in changed tissue composition? | amp amp there |
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Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | Question Quest# C | 8Vb5 | stems play in 8Vb7 4 gravity? | to a signer | ponsible for 8VI6 ution, and proteins in | What are the effects of space-induced endocrine 2b1 dhanges on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | 2 14 | 3a3 |
| | Question Quest# C | What is the role of gravity on sensory thresholds 8Vb5 (audition, visual, taste, pain)? How do endocrine, neurohumoral, and metabolic mechanisms influence this effect? | What role do endocrine and neural systems play in 8Vb7 4 controlling/modifying adaptation to gravity? | What are the systemic, local, cellular, and 8VI2 4 subcellular mechanisms involved in adaptation to altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | ponsible for 8VI6 ution, and proteins in | What are the effects of space-induced endocrine 2b1 changes on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | 2 14 | 3a3 |
| | Quest# C | 8Vb5 | stems play in 8Vb7 4 gravity? | to a signer | What are the biochemical pathways responsible for 8V16 synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to altered gravity? | What are the effects of space-induced endocrine 2b1 dhanges on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, and energy metabolism)? | *4 What are the effects of microgravity on renal 2f4 1 function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion, and excretion? | What are the cardiovascular responses to extravehicular activity (EVA) at various levels of gravity (e.g., microgravity, planetary surface exploration)? What factors influence the occurrence, magnitude, and sequence of these |

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| Question Quest# C | long-term space flight, are there delayed 3a12 tent consequences, either beneficial or As a corollary, are there appropriate tive measures that should be applied both aar-term (hours to days) and long-term to vears) after flight? | Which pulmonary life support procedures should be 3b3 1 used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary | What procedures and approaches prevent 4c2 1 decompression sickness or minimize crew risk? | Treatment of medical problems of spacecraft inner 4c3 temperature, and adverse effects of the gaseous environment? | What are the risks for bubble formation and clinical 4c9 decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? | Does the atrophy from unloading make muscle, 5a9 1 tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | What potential risks does bone loss present to the 5c4 1 development of bone fractures, hypercalcemia, metastatic calcification, and renal stone formation? | 5 How are risks associated with acute exposure to 7g6 1 space radiation to be managed medically? |
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| Quest# | long-term space flight, are there delayed 3a12 tent consequences, either beneficial or As a corollary, are there appropriate tive measures that should be applied both aar-term (hours to days) and long-term to vears) after flight? | Which pulmonary life support procedures should be 3b3 1 used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary | 3 * What procedures and approaches prevent 4c2 1 decompression sickness or minimize crew risk? | 3 * Treatment of medical problems of spacecraft inner 4c3 1 temperature, and adverse effects of the gaseous environment? | What are the risks for bubble formation and clinical 4c9 decompression sickness associated with various pre-EVA denitrogenation/decompression schedules and exercise? | 3 * 4 Does the atrophy from unloading make muscle, 5a9 1 tendon, and the myotendinous junction more susceptible to injury or damage on resuming normal weight-bearing states? | *4 What potential risks does bone loss present to the 5c4 1 development of bone fractures, hypercalcemia, metastatic calcification, and renal stone formation? | 3 * 5 How are risks associated with acute exposure to 7g6 1 space radiation to be managed medically? |

Table

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| j | ວັ | ₹ .⊑ | _કે કુ | There is an increase in cardiac arrhythmias associated with space flight and, if so, what are the specific mechanisms responsible for them? | ă t | Since microgravity afters blood pressures and flows to some tissues, what are the structural a functional consequences in these various these. | and organ systems with long-duration flights? What is the effect of long-duration space flights on the human immune system? (Reg. Physiol see p. 6) | How completely and how well does injured muscle repair in microgravity? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Table 7 Critical Questions That Would Utilize A Lunar Base Lunar Base

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| | 5 Critical Question | What are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can attered gravities affect fertilization, and do these results indicate more general mechanisms of membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? | npensatory , organ, circulatory, Vhat is the interaction is gravity's effect on | narmacokinetics (absorption, abolism, and elimination) of drugs I in space? Which methods of ugs are the most effective in lictable response during space | pace flight alter gastrointestinal function, ig the absorption of essential nutrients and ctioning of gut flora? What are the effects ie flight on liver function? Are the effects |
| | | at to do do on in in | | sgu | Does space flight alter gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects |
| | C4 C5 Critical | S What are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can attered gravities affect fertilization, and do these results indicate more general mechanisms of membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? | How does gravity affect compensatory mechanisms (e.g. endocrine, organ, circulatory, regenerative processes)? What is the interaction with growth stages? What is gravity's effect on wound healing? | What are the pharmacokinetics (absorption, distribution, metabolism, and elimination) of drugs likely to be used in space? Which methods of administering drugs are the most effective in providing a predictable response during space flight? | |
| | | What are the effects on the male and female germ cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can these results relate to the proliferation and differentiation of other individual cell types? — Can attered gravities affect fertilization, and do these results indicate more general mechanisms of membrane alteration in individual cells? — Which responses are transmitted maternally, and which are intrinsic to the developing embryo? — What are the results of altered gravity fields on the axis polarity and symmetries of the zygote? — Are there gravity effects that can terminate in changes of gene activation? | | sgu | Obes space flight alter gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects |

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | C2 C3 C4 C5 Critical Question | What are the time course and magnitude of fluid shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during return to 1 g after flight? | What are the time course and magnitude of the diuresis, natriuresis, and kaliuresis resulting from exposure to hypogravity? | What is the role of gravity on thirst and feeding behaviors (appetite, taste preference, and thresholds)? | To what extent has chemical evolution of the biogenic elements and compounds occurred on planets other than Earth, and why did it take different courses? | What evidence is there for the presence of biogenic compounds of abiotic origin in planetary materials, including Earth? | What is the history of effects on biological evolution that have been exerted by extraterrestrial phenomena? | What are the acute and long-term effects of the space environment on sleep architecture, quantity, and quality? | What are the mechanisms regulating thirst and electrolyte appetite during space flight? | What are the uses of microgravity for better understanding of cardiovascular function on Earth? | What are effects of weight bearing on development? |
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Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| C r 11 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| E | 4 | | | 6a8 4 | | | | *** |
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| C r 11 | tand 6a4 4 | 6a5 4 | 6a7 4 | by 6a8 4 | 6c2b 4 | 6d1 4 | tion 6d3 4 | 81117 4 |
| C r 11 | tand 6a4 4 | 6a5 4 | 6a7 4 | by 6a8 4 | 6c2b 4 | 6d1 4 | tion 6d3 4 | 81117 4 |
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| Question Quest# Cr1 | ronal models can be used to understand 6a4 4 ocessing and adaptation in altered nal states? | gaze, body orientation, onverge? What are the | n neural 6a7 4 sleep, and | 6a8 4 | subcortical neural 6c2b 4 did exocentric | structure-function relationships of 6d1 4 gans and canals, including plasticity, and degeneration? | tion 6d3 4 | ity affect organogenesis and the fanatomical structures? avity sensitive systems (i.e. prioceptive, cardiovascular, l) of young and adult animals iive to this stimulus in ontogeny? |
| Question Quest# Cr1 | ronal models can be used to understand 6a4 4 ocessing and adaptation in altered nal states? | At what sites do signals from the different faceptors involved in gaze, body orientation, posture and motion converge? What are the | n neural 6a7 4 sleep, and | by 6a8 4 | ural 6c2b 4 | 6d1 4 | tion 6d3 4 | 81117 4 |
| Question Quest# Cr1 | ronal models can be used to understand 6a4 4 ocessing and adaptation in altered nal states? | At what sites do signals from the different faceptors involved in gaze, body orientation, posture and motion converge? What are the | Characteristics of this convergence: Does altered gravity lead to changes in neural control of biological rhythms, such as sleep, and temperature? | by 6a8 4 | ural 6c2b 4 | 6d1 4 | tion 6d3 4 | 81117 4 |
| Question Quest# Cr1 | ronal models can be used to understand 6a4 4 ocessing and adaptation in altered nal states? | At what sites do signals from the different 6a5 4 receptors involved in gaze, body orientation, posture and motion converge? What are the | Control of biological rhythms, such as sleep, and temperature? | 4 * What changes are produced in the visual system by 6a8 4 altered states of gravity? | • What are the cortical and subcortical neural 6c2b 4 correlates of egocentric and exocentric orientation? | What are the structure-function relationships of 6d1 4 the otolith organs and canals, including development, plasticity, and degeneration? | 4 * What are the biophysical and physiological 6d3 4 mechanisms of vestibular hair cell transduction and the physiology and pharmacology of transmission? | How does gravity affect organogenesis and the development of anatomical structures? — Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular, musculoskeletal) of young and adult animals similarly sensitive to this stimulus in ontogeny? |
| Question Quest# Cr1 | ronal models can be used to understand 6a4 4 ocessing and adaptation in altered nal states? | 3 4 * At what sites do signals from the different 6a5 4 receptors involved in gaze, body orientation, posture and motion converge? What are the | Characteristics of this convergence: Does altered gravity lead to changes in neural control of biological rhythms, such as sleep, and temperature? | * What changes are produced in the visual system by 6a8 4 altered states of gravity? | • What are the cortical and subcortical neural 6c2b 4 correlates of egocentric and exocentric orientation? | What are the structure-function relationships of 6d1 4 the otolith organs and canals, including development, plasticity, and degeneration? | 3 4 * What are the biophysical and physiological 6d3 4 mechanisms of vestibular hair cell transduction and the physiology and pharmacology of transmission? | How does gravity affect organogenesis and the development of anatomical structures? — Are the gravity sensitive systems (i.e. vestibular, proprioceptive, cardiovascular, musculoskeletal) of young and adult animals similarly sensitive to this stimulus in ontogeny? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

Table 7

Critical Questions That Would Utilize A Lunar Base

| Criticality |
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| and |
| Category |
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| 20 20 20 4 4 4 4 4 4 4 4 5 5 5 5 5 5 5 5 6 5 6 6 6 6 | | | | 73 | | | | | |
| 20 c c c c c c c c c c c c c c c c c c c | | l | What are the long-term effects of the space environment on the interaction between the circadian system and ultradian and infradian rhythms, especially reproductive systems? | What are the hypothalamic-pituitary-adrenal and opioid system responses to normal space-flight events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, and environmental stimuli? | What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | How do attered biological rhythms associated with long-term space flight affect hormone secretion and function and vice versa? | e G | Does space flight affect the humoral or cell-mediated immune functions, nonspecific immunity, or immune surveillance capabilities of space crews in a manner that would expose them to unacceptable medical risk while on a mission. | upon return to Earth, or as a consequence of |
| 8 8 - 8 | | l | What are the long-term effects of the space environment on the interaction between the circadian system and ultradian and infradian rhythms, especially reproductive systems? | What are the hypothalamic-pituitary-adrenal and opioid system responses to normal space-flight events (e.g. EVA, countermeasures) as well as to reference "standardized" physical, emotional, and environmental stimuli? | 5 * What are the acute and chronic effects of space flight on endocrine system homeostasis and responsiveness? | 5 'How do altered biological rhythms associated with long-term space flight affect hormone secretion and function and vice versa? | e G | 5 Does space flight affect the humoral or cell-mediated immune functions, nonspecific immunity, or immune surveillance capabilities of space grews in a manner that would expose them to unacceptable medical risk while on a mission. | upon return to Earth, or as a consequence of |
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Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

| | | | | | | | | | | | | | | ŀ | ŀ | ŀ | | | ľ | ŀ | ŀ | ŀ | ŀ | - | | | ſ |
|---|---|----|----------|--------------|---|--------|----|---|---|---|---|---|----------|----|-----------|-----|---|----|---|---|--------------|---|---------------|-----|----------|----------|------|
| ਹ | ਲ | පී | δ | Ö | C1 C2 C3 C4 C5 Critical Question | Quest# | ပ် | | 2 | 8 | 2 | 9 | _ | 80 | <u></u> 6 | 의 | Ξ | 12 | 5 | 4 | 151 | 9 | 7 | 8 | Group w/ | v/ other | Disc |
| | 2 | | 4 | 2 | 5 * What are the time course and magnitude of | 2d2 | 4 | | | | | | × | × | × | | × | × | - | - | - 2 | 2 | | | | | |
| | | | | | space-flight-induced changes in the surface | | _ | | _ | | | | | | | | | | | | | | | | | | |
| | | | | | phenotypes (subpopulations), circulation patterns, | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | or functional capacities of the cells of the immune | | | | | | | | | | _ | | | | | | | | _ | | | | |
| | | | | | system, including mucosal, humoral, cell-mediated | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | and immune surveillance systems? | | | | | | | | _ | | | | | | | - | | | | | | | |
| | | _ | | | What factors cause or otherwise influence the | | | | | | | _ | | | | | | | | | | _ | | | | | |
| | | | | | consistently demonstrated post-flight reduction in | | | | | - | | | | | | | | | | | | | | _ | | | |
| | | | | | blastogenic responsiveness to nonspecific mitogens | | | | | | | | _ | | | | | | | | _ | | - | | | | |
| | | | | | (PHA, Con A, LPS)? | | | | | | | | | | | - | | | | | | | | | | | |
| | | | | | What are the dynamics of the leukocyte count | | | | | | - | | | - | | | | | | | | | | _ | | | |
| | | | | | during space flight with respect to: | | | | | | | | | | _ | _ | | | | | | | | | | | |
| | | | | | - Induction of neutrophilia, lymphopenia, | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | monocytopenis or eosinopenia | | | | | | _ | | | | | | | | | | | | | | | | |
| | | | | | lanten to vincenso landinative andmire | | | | - | | - | | | | | | | | | | | | | | | | |
| | | | | | Tighting and informal capacity of flating | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | _ | | | | _ | | | | | | | | | | | | | |
| | | | | | other changes in the WBC differential count, or | | | | - | | _ | | | | | | | | | | | | | | | | |
| | | | | | the circulation/sequestration of immunologically | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | active cells? | | | | | | | | | | | | | | | | | | | | | | |
| | | | 4 | Ŋ | 5 * What are the effects of space flight on the | 2d7 | 4 | | | | | | × | × | <u>×</u> | | | × | | | - | _ | - | | | | |
| | | | | | functional capacities of the effector/accessory | | | | | | | | _ | | | | | | | | | | | | | | |
| | | | | | cells of specific or nonspecific immunity | | | | | | | | | | _ | | | | | | | | | | | | |
| | | | | | (monocytes, neutrophils, macrophages, | | | _ | | | | - | | | | | | | | _ | | | | | | | |
| | | | | | lymphocytes, and NK cells)? | | | | | _ | _ | | | _ | | | | | | | | | _ | | | | |
| | | | | S | *Do any of the changes in the immune system | 2d8 | 4 | | | _ | | | × | × | č | | | × | | | _ | - | <u>-</u> | | | | |
| | | | | | predispose crewmembers either during or after | | | | | | - | | | | | | | | | | | | | | | | |
| | | | | | flight to infectious diseases, alleraies, or delays in | | | _ | | | | | | - | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | Ľ | What are the energy requirements of EVA? What | 296 | 4 | | | | | | <u>×</u> | × | <u>×</u> | • • | | × | | | _ | _ | '' | - 8 | | | |
| | | | |) | are the effects of deconditioning. EVA. and | ! ! | | | | | | _ | _ | | | | _ | | | | | | | | | | |
| | | | | | countermeasures on nutritional requirements and | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | body composition during space flight? | | | | | _ | | | | | | | | | | | | | | | | | |

Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

| ſ | ľ | ľ | t | L | | | | | | | | | | | | | | | | | | | | | | | |
|---|----------|---|--------------|--------------|--|--------------|-------|--|---|-------------|-------------|---|---|----------|----|----------|----------|----|----|----|-------------|---------------|--------------|-------------|----------|---------|------|
| 5 | C2 C3 C4 | ខ | 3 | ၓ | C5 Critical Question | Quest# | C r11 | 1 2 | 3 | 4 | 3 | 9 | 7 | 8 | 6 | - | = | 12 | 13 | 14 | 15 | 16 | 17 | 8 Gre | Group w/ | / other | Disc |
| | 2 | | 4 | Ŋ | 5 • Are there valid ground models and analogs for the study of the effects of space flight on nutrition? | 297 | 4 | | L | | | ļ | × | × | × | | <u> </u> | × | | | 2 | - | 2 | | | | T |
| | 2 | | 4/ | ົທ | 5 What is the optimal presentation, nutritional and caloric formulation of the diet for maintaining | 269 | 4 | | | <u> </u> | | | × | × | × | | | × | | | _ | _ | <u> </u> | | | | |
| | | | | | | | | | | | | | | | | | | | | | | • | | | | | |
| | | - | | | are the behavioral and performance responses of individuals to particular food constituents during | | | | | | | | | | | | | | | | | | | | | | |
| | | , | · | | space flight? Are there changes in dietary preference? | | | | | - | | | | | | | | | | | | | | | | | |
| | | | u) | ູດ | 5 • Is there a change with respect to "food allergies" or other abnormal reactions to foodstuffs? | 2e10 | 4 | | | | | | × | <u>×</u> | × | | | × | | | _ | - | - | | | | |
| | | | (2) | | 5 What are the effects of space-flight-related | 2012 | 4 | | | | | | × | <u>×</u> | × | × | × | × | | | | <u> </u> | | | | | |
| | | | | | ractors, (e.g. bone demineralization and light spectrum) on nutritional requirements? | | | | | | | | | | | | | | | | | | | | | | |
| | 8 | | rt) | 'n | 5 * What changes in carbohydrate/lipid metabolism occur during space flight? Are they modified by | 2e13 | 4 | | | | | | × | × | × | × | | × | | | | <u> </u> | | | | | |
| | | | | | dietary intake? | | | | | - | | | | | | | | | | | | | | | | | |
| | 8 | 4 | ك | ις. | 5 * What are the relationships of fluid and electrolyte responses to space flight on sensory thresholds and space motion sickness? | 2f11 | 4 | | | - | | | × | × | × | - | | × | | | | | | | | | |
| | | 4 | 4 ت | د | 5 To what extent does the qastrointestinal system modify electrolyte and fluid balance control during space flight? | 2f13 | 4 | | | | | | × | × | × | × | | × | | | | | | | | | |
| _ | | 4 | 4 ت | ro • | What are the compounded effects of microgravity and EVA on thermoregulatory processes and heat exchange? | 2 g 2 | 4 | <u>. </u> | | | | | × | × | _× | | | × | | | | - | | | | | |
| | | 4 | | ις. | 5 How does the regulation of body temperature change during space flight? How do these changes | 295 | 4 | | | _ | | | × | × | × | × | | × | | | | | - | | | | - |
| | | | | | affect the response to thermal load? | | | | | | | | | | | | | | | | | | _ | | | | |

Table 7

Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

| 1 ' | H | T | H | | | | , | . | | | | | | | | | | | | | | | | | | | |
|-------------|---|----------|----------|---|--------|---|-------------|--|-----|---|---|---|---|-------------------|----------|------------|----|---|-------------|-------|-------------|------|----|----------|------|------|---------------------------------------|
| ' \ | 2 | <u> </u> | ₹ | CI C2 C3 C4 C5 Critical Question | Quest# | Ü | 1 | 2 3 | 3 4 | 2 | 9 | 4 | 8 | 6 | e | Ξ | 12 | 3 | 4 | 51 | 6117 | 7 18 | | Group w/ | | a #c | ا اق |
| | | | ų) | Considering development as a series of stages or phases, beginning with pattern specification, and progressing through differentiation, how will gravity affect selected phases in animals that represent different species and phyla? — How will gravitational fields, particularly microgravity, disturb the precise coordination and postural control required in mating? — Will aquatic animals perceive and respond to gravity as do their terrestrial counterparts? Those animals which pursue different life stages in both environments may be particularly valuable | 81115 | 4 | | | | | | × | × | × | × | × | × | | | · 0 | | | | | | E . | |
| | | | - C2 | | 91116 | 4 | | | | | | × | • | × | × | × | × | | | - 74 | | | ტ | 4 | | | |
| | | | rc . | t-young interactions be attered in ronment? 19 or parturition occur normally? 19 the effects on lactation, suckling ent- young bonding mechanisms? 19 of rapid post-natal growth, which e most sensitive to altered gravity | 011110 | 4 | | | | | | × | | × | × | × | ~ | | _ | Ν | | · | က် | 4, بې | 7, 8 | œ | · · · · · · · · · · · · · · · · · · · |
| | | | <u> </u> | | 811111 | 4 | | · | | | | × | | $\frac{}{\times}$ | × | × | | | | Ν | | _ | | | | | |
| | | | ည် | um in terms of | 8lVa1 | 4 | | | | | | × | | × | <u>×</u> | <u>×</u> _ | | | | | | | ω, | 10 | | | |
| $\neg \neg$ | | | 2 | 5 * What is the role of gravity in the evolution of animal gravity sensors? | 8IVa2 | 4 | | ······································ | | | | × | × | _ <u>×</u> | <u>×</u> | <u>×</u> | | | | | | _ | | 9 | | | |
| | | | | | | 1 | - | 4 | _ | | | _ | - | - | - | - | - | - | _ | | _ | | | | | | _ |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Cniticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

| <u>0</u> | | ا ا | 1 N | 18 | C1 C2 C3 C4 C5 Critical Question | Quest# | C 1-1 | 7 | 3 4 | - 2 | 9 | 4 | 8 | 6 | 10 | 11 | 12 | 13 | 4 | 151 | 6 1 | 711 | 8 | Group w/ | / other | r Disc | 1 |
|----------|-------------|--------|----------|--------------|---|--------|-------|---|---------------------------------------|-----|----------|----------|---|---|----------|----------|----|----|---|--------------|-----|--------------|----------|----------|---------|--------|---|
| | | | LO. | ic | 5 • What are the basic properties and fundamental mechanisms that permit gravity sensors to adapt to an aftered g-environment? | 8IVa3 | 4 | | | | | × | × | × | × | × | × | | | - | | - | - α | | | | |
| | _ | | Ω. | * | 5 • Will animals bred for many generations in altered-g show phenotypically different gravity sensors? | 8IVa4 | 4 | | | | <u> </u> | | | × | × | × | × | | | - | 2 | | ω | | | | |
| | | | ro. | 10 | 5 • Is there a relationship between otoconial or statolith load and the acceleratory environment, and/or between this load and the neural substrate? | 81Vc5 | 4 | | | | | × | × | × | × | × | × | | | - | | | <u> </u> | | | | |
| | | | ഹ | * | 5 • What are the principles of organization, and the inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are placed in altered-g environments? Are there restrictive mechanisms in some species that prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) | 8IVd1 | 4 | | | | • | × | × | × | × | × | × | | | - | | _ | <u></u> | | | | |
| | | | <u> </u> | * | 5 • Will otoconial and/or statolith load change in a sustained, altered gravitational environment, and will the response be uniform across phyla and species? | 81745 | 4 | | | | | × | × | × | × | × | × | | | + | N | - | | | | | |
| | | | LO | * 10 | 5 • Does development of a gravity receptor in an attered-g environment affect the ability of the animal to mature and reproduce? | 8IVe1 | 4 | | · · · · · · · · · · · · · · · · · · · | | | × | | × | × | × | × | | | _ | _ | ` | <u>8</u> | 0 | | | |
| | | | un . | . | Would gravity sensors of animals bred in a sustained, altered gravitational environment be different structurally and functionally from those of animals bred on Earth? Would the changes be | 81Ve2 | 4 | | · · · · · · · · · · · · · · · · · · · | | | <u>×</u> | | × | × | × | × | | | - | _ | ** | | 8, 10 | | | |
| | | | ų) | ب | 5 • Are there species differences in degree of susceptibility to a developmental change in an altered-g environment? | 81Ve5 | 4 | | | | | <u>×</u> | × | × | <u>×</u> | <u>×</u> | × | | | | - | - | - | 8, 10 | | | |

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Critical Questions That Would Utilize A Lunar Base Listed by Category and Criticality

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| | c r | 81Ve6 | 81Vf1 | 81Vf2 on 1? | 8Va2 | 8Vb6 | 8Vb8 | 8Vb11 | 8Vb12 | 8VI3 |
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| | Question Quest# Cr | ace 8IVe6 rce? | ure the mechanisms that permit central 81Vf1 tion to novel inputs from gravity sensors in red-g environment? Does rewiring take | 81Vf2 | n the 8Va2 | 8Vb6 | 8Vb8 | 8Vb11 | If so, how 8Vb12 | 8VI3 |
| | Question Quest# Cr | 81Ve6 | 81Vf1 | 81Vf2 on 1? | the 8Va2 | 8Vb6 shanisms, | How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 | * Is gravity necessary for sex behavior? If so, how 8Vb12 does gravity affect it and what are the mechanisms? | Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? |
| | Question Quest# Cr | 81Ve6 | 81Vf1 | 81Vf2 on 1? | the 8Va2 | 8Vb6 shanisms, | How does gravity affect endocrine and exocrine 8Vb8 processes? Neuro- axonal transport? Transitter release and re-uptake processes? | 8Vb11 | * Is gravity necessary for sex behavior? If so, how 8Vb12 does gravity affect it and what are the mechanisms? | Is the musculoskeletal cyto-architectural 8VI3 organization and responsiveness to physiological and mechanical stimuli altered by gravity? |
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Table 7

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| - | 8VI12 4 | | 8VI16 4 | | | 11a1 4 | | 11a2 4 | | | 11a3 4 | | | | | 11a4 4 | | | | | 11a5 | | | 11011 4 | | |
| Question Quest# Cr1 | ationship between muscle and bone 8VI12 | necessary for an integrated response to altered gravity or do the systems respond independently? | 8VI16 | musculoskeletal systems of rats, monkeys, and humans to altered gravity are similar and which | | its 11a1 | evolution in circumstellar, interstellar, and | 11a2 | ar, | interstellar and interplanetary dust? | 11a3 | processes in the ptotosolar nebula for altering | pre-existing materials and producing new | compounds and phases containing the biogenic | elements? | 11a4 | bodies modified the distribution, structure, and | composition of pre-existing compounds and phases | and provided mechanisms for production of new | species? | 11a5 | of presolar and nebula products in existing | | *Under what conditions could methane or carbon 11b11 | monoxide, rather than carbon dioxide, have been | supplied as the dominant carbon source at Earth's |
| Question Quest# Cr1 | ationship between muscle and bone 8VI12 | | 8VI16 | musculoskeletal systems of rats, monkeys, and humans to altered gravity are similar and which | | and its 11a1 | evolution in circumstellar, interstellar, and | structure and | ar, | interstellar and interplanetary dust? | | processes in the ptotosolar nebula for altering | pre-existing materials and producing new | compounds and phases containing the biogenic | elements? | ы 11a4 | bodies modified the distribution, structure, and | composition of pre-existing compounds and phases | and provided mechanisms for production of new | | position 11a5 | of presolar and nebula products in existing | | 11611 | monoxide, rather than carbon dioxide, have been | supplied as the dominant carbon source at Earth's |
| Question Quest# Cr1 | ationship between muscle and bone 8VI12 | | 8VI16 | musculoskeletal systems of rats, monkeys, and humans to altered gravity are similar and which | | its 11a1 | evolution in circumstellar, interstellar, and | 11a2 | ar, | interstellar and interplanetary dust? | 11a3 | processes in the ptotosolar nebula for altering | pre-existing materials and producing new | compounds and phases containing the biogenic | elements? | 11a4 | bodies modified the distribution, structure, and | composition of pre-existing compounds and phases | and provided mechanisms for production of new | | 11a5 | of presolar and nebula products in existing | | *Under what conditions could methane or carbon 11b11 | monoxide, rather than carbon dioxide, have been | supplied as the dominant carbon source at Earth's |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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TABLE 8

CRITICAL QUESTIONS THAT WOULD UTILIZE ROBOTIC MISSIONS LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- 3 * Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- 4 = Science Specifically enabled by Moon and/or Mars Missions.
- 5 = Basic Research Not Directly Applicable to Moon and/or Mars Missions.
- Indicates primary category of application.

CRITICALITY

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Yes

No

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.
- *Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.
- Science Readiness Levels Only folklore of practitioners and anecdotal data available Basic scientific concept formulated Ground models developed, flight validation required Flight validation performed Countermeasures identified Countermeasures tested Operational requirements established **Technology Readiness Levels** Technology need identified Technology and conceptual solution available Component and/or breadboard validation in laboratory environment exist Flight validation performed Systems/subsystem prototype demonstration in a relevant ground or space environment completed System prototype demonstrated in a space environment Actual system completed and flight qualified through test and 7. Demonstration Actual system "flight proven" through successful mission 8 operations dule (information required by) Near term < 5 years Mid term 6-10 years Far term > 10 years **Effort Required** Substantial Moderate Low Defined Sequence (Clearly defined sequential path for scientific investigation exists) Yes No Parallel/Alternative Path (are parallel or alternative pathways

Ground-based research required

Spacelab would be used for research

Space Station Freedom would be used

Spacelab needed for Extended Duration Orbiter

Centrifuce SSF Centrifuge Facility would be used Free Flyer 11. Free flyer biosatellite Lunar Base Lunar base would be used 13. Robotic Explorer Robotic explorer would be used Other Requirements Requirement for flight resources other then those identified in 8-10 Flight Validation Required Flight validation required Not required Facilities Sufficient 16. Current ground facilities (NASA Centers, Universities and provide industry) are sufficient. Current ground facilities insufficient 17. Community Sufficient There is a sufficient scientific community already committed or recruitable Scientific community is insufficient **Attract New Community** Activity will attract new scientists Activity will not attract new scientists Group with other disciplines (can this activity be grouped with others from different life science disciplines?) No, cannot be grouped Do not know at this time Behavior, Performance and Human Factors Regulatory Physiology Cardiopulmonary Environmental health 7. Musculoskeletzi Neuroscience 8 Redistion Health Q Cell and Developmental Biology 10

Plant Biology

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Table 8 Page

Critical Questions That Would Utilize Robotic Missions Listed by Category and Criticality

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| - | | | | What will the radia space vehicle and energy, and linear radiation? | What will the radiation environment be within the space vehicle and what factors influence the flux, energy, and linear energy transfer spectra of the radiation? | 7a8 | 1 | 4 | - | - | 8 | 8 | | × | × | | × | <u>^</u> × | × | 0 | _ | _ | _ | | | | | |
| - | | | | How can protection a cosmic rays and the events be improved? | gainst the effects of galactic proton radiation of solar | 7a9 | - | - | ტ | - | - | _ | × | × | × | | × | <u>^</u> × | × | 7 | | | - | | | | | - |
| - | | <u>е</u> | 4 | What requirements human missions (« Mars with respect imported from Ea | ould be placed on robotic and ters and landers) to protect biological contamination (forward contamination)? | 10 1 | <u> </u> | 8 | - | ო | | <u>£</u> | × | | × | | × | × | × | Ν | 8 | N | | 13, | 4 | | | |
| - | | | 4 | Are there unique interactions radiation (or other environme microgravity that affect the thiological evetame in snace? | | 8168 | 2 | <u>~</u> | - | т | | <u>£</u> | × | × | × | × | × | × | × | | N | N | | <u></u> | | | | - |
| | | | 4 | How is the effect cells influenced by | (and microgravity) on fields and radiation? | 811c1 | ~ | - | | - | ٧ | ო | × | × | × | × | × | × | × | | 2 | - 2 | | 6 | | | | |
| * | | e e | 4 | What provisions me robotic and humar from harm caused materials from Ma | Ĵ C | 10 2 | ო | 2 | - | | ო | ო | × | | × | | × | × | × | _ | N | | | | | | | |
| - | · N | m | 4 | What are the factors automated systems w promote productivity significant issues of human operators, and particular missions? | What are the factors involved in integrating automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and countermeasures for particular missions? | 141 | - | - | <u>ო</u> | - | ო | m | × | × | × | | | × | × | | α | 2 | - | N | | | | |
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Critical Questions That Would Utilize Robotic Missions Listed by Category and Criticality

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| J | Ę | What bounds do the energetics and dynamics of accretion and core formation place on the time when surface temperatures became suitable for the occurrence of liquid water? | What geological settings were conducive to th origin of life? | What were the earliest products of the intera of liquid water or atmospheric gasses or both crustal rocks? | at π ulyst | at pl ospt | at w gen | spa | nica e b | hat Ven osp | that snic sts (|
| | <u>5</u> | age ¥ the the | ¥ orig | What were the earliest products of the intera of liquid water or atmospheric gasses or both crustal rocks? | What minerals were available as potential chemical catalysts in the boundary regions? | What photochemical processes occurred in the atmosphere, at the interfaces of the atmosphere with oceans and land, and in surface waters? | What were the products and rates of carbon and nitrogen fixation by photochemical or other processes? | What was the nature of the earliest geochemical cycles of the biogenic elements and over what tinand space scales did they operate? | What redox couples could have supplied sources of chemical free energy in various geophysically active boundary regions over time? | In what ways was Earth unique, relative to Mars and Venus, in its ability to evolve and maintain its hydrosphere? | To what extent has chemical evolution of the biogenic elements and compounds occurred on planets other than Earth, and why did it take different courses? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Robotic Missions Listed by Category and Criticality

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| _ | | | | compounds of abiotic origin in planetary materials, | | | | | | - | | | | | | | | | | | | | | | |
| | | | | including Earth? | | | | | - | , | | | | | | | | | <u> </u> | _ <u>-</u> | | | 6 | 7 | |
| | | 4 | | How did carbon chemistry lead to self-replicating | 11616 3 | <u>ო</u> | _ | ٠. | | e | <u>×</u> _ | | | | | | < | - | <u> </u> | | | <u>-</u> | | | |
| _ | | | | systems? | | | | | | | | | | | | | ; | | | | _ ` | | | • | |
| | _ | 4 | | In what ways have physical changes in the | 1101 | <u>ო</u> | <u>~</u> | ç. | - | - | <u>×</u> | | | | | | | | N . | | | <u>-</u> | <u>.</u> | ŧ | |
| | _ | | | planetary surface environment influenced both the | | | | | | | | | | | | | | | | - | | _ | | | |
| | | | | rate and the direction of early microbial evolution? | | | | | | | | | | | | | | | | | | | | | |
| _ | | 4 | | What is a geological time scale for major events in | 11c2 | 3 | <u>ر.</u> | ~ | _ | - | <u>×</u> | | | | | | × | | 7 | | | - - | - က် | 4 | |
| - | | | | biological evolution? | | | | | | | | | | | | | | | | | | | | , | |
| | | 4 | _ | How have the evolving biota, in turn, modified and | 1103 | 3 | <i>د-</i> | ٠. | - | е Т | × | | | | | | × | | N_ | | | <u>-</u> - | <u>.</u> | <u> </u> | |
| | | | | modulated their environments over time? | | | | | | | _ | | | | | | ; | | | | | | | • | |
| | | 4 | <u>.</u> | What are the biochemical and genetic properties of | 1104 | 9 9 | <u>۰</u> . | <u>٠</u> | - | ر د | ×_ | | | | | | × | | N | _ | | | <u>.</u> | <u>+</u> | |
| | | | | the universal ancestor of all life and from these | | | | | | | | | | | | | | | | | | | | | |
| | | | | properties the characteristics of its environment? | | | _ | | | | | | | _ | | | | | | , | , | | | • | |
| _ | _ | 4 | . | What is the correlation between the historical | 1101 | 9 9 | <u>٠.</u> | ٠. | _ | <u>က</u> | <u>×</u> _ | | | | | | × | | N | _ | _ | - | <u>.</u> | t | |
| | | | | pattern of biological evolution among complex | | | _ | | | | | | _ | | | | | | | | | | | | |
| | | | _ | fossil organisms and geological record of | | | | | | | | | | | | | | | | | | | | | |
| | | | | environmental change? | | | | | | | | | _ | | | ; | ; | | _ (| , | | | 40 | 5 | |
| | | 4 | • | What is the history of effects on biological | 11d2 | ى 4 | 60 | ٠. | _ | <u>-</u> | <u>×</u> - | _ | | | | <u>×</u> _ | Κ_ | | N | _ | _ | _ | <u>.</u> | <u>t</u> | |
| _ | _ | | | evolution that have been exerted by | | | | | | _ | | | | | | | | | | | _ | | | | |
| | | | | extraterrestrial phenomena? | | ㅓ | \dashv | _ | | | \dashv | \dashv | 4 | 4 | 4 | 4 | | | | | | | | | |

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Table

Critical Questions That Would Utilize Robotic Missions Listed by Category and Criticality

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| | | _ | 4 | | | The highest priority in the category requiring | 4445 | ٤ | Ŀ | ۲ | ١, | Į, | Ι. | | : | T | \dagger | t | t | t | + | ╀ | + | + | 1 | _ | | - 1 | 3 |
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| | • | | | | | main missions is accorded to studies of Mars. | | | | | | | | | | _ | - | | _ | _ | | | | _ | | | | | |
| | | _ | | | <u> </u> | Conduct chemical, isotopic, mineralogical, | | | | | | | | | | | | | _ | _ | | _ | | | | | | | |
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CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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TABLE 9

CRITICAL QUESTIONS THAT WOULD UTILIZE FREE FLYERS LISTED BY CATEGORY AND CRITICALITY

CATEGORIES

- 1 * Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and planetary environments.
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- 3 = Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- 4 = Science Specifically enabled by Moon and/or Mars Missions.
- 5 = Basic Research Not Directly Applicable to Moon and/or Mars Missions.
 - Indicates primary category of application.

CRITICALITY

SSF

- Criticality 1: Consensus that answer is required for Mars mission. (known effect and known problem for mission).*
- Criticality 2: Answers might be required, science basis to evaluate risk is not adequate.*
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Criticality 4: Important science which is relevant to exploration mission.

Space Station Freedom would be used

*Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| | Science | e Read | iness Levels | 10. | Centri | uge | |
|---|---------|-----------|--|-----|----------|---------------|--|
| | 1. (| Only fol | dore of practitioners and anecdotal data available | | X | - | SSF Centrifuge Facility would be used |
| | 2. E | Basic so | ientific concept formulated | 11. | Free F | lyer | |
| | 3. (| Ground | models developed, flight validation required | | X | - | Free flyer biosatellite |
| | | | lidation performed | 12. | Lunar | Base | |
| | 5. (| Counter | measures identified | | X | - | Lunar base would be used |
| | 6. (| Counter | measures tested | 13. | Roboti | с Ехр | |
| | 7. | Operation | onal requirements established | | X | - | Robotic explorer would be used |
| | | | eediness Levels | 14. | Other | Requi | irements |
| | | | ogy need identified | | X | = | Requirement for flight resources other then those |
| | | | ogy and conceptual solution available | | | | identified in 8-10 |
| | | | nent and/or breadboard validation in laboratory | 15. | Flight 1 | Valida | ition Required |
| | | noniva | ment exist | | 1. | - | Flight validation required |
| | 4. F | Flight v | alidation performed | | 2 | = | Not required |
| | 5. 5 | System | s/subsystem prototype demonstration in a relevant | 16. | Faciliti | es Sui | ifficient |
| | | | or space environment completed | | 1. | - | Current ground facilities (NASA Centers, Universitie |
| | 6. | System | prototype demonstrated in a space environment | | | | and provide industry) are sufficient. |
| | 7. | Actual s | ystem completed and flight qualified through test an | d | 2 | - | Current ground facilities insufficient |
| | | Demon | | 17. | Comm | unity : | Sufficient |
| | 8. 7 | Actual s | ystem "flight proven" through successful mission | | 1. | - | There is a sufficient scientific community already |
| | | oberatio | | | | | committed or recruitable |
| | | | ormation required by) | | 2 | - | Scientific community is insufficient |
| | 1. | | Near term < 5 years | 18. | Attract | New | Community |
| | 2 | - | Mid term 6-10 years | | 1. | _ | Activity will attract new scientists |
| | 3 | _ | Far term > 10 years | | 2. | - | Activity will not attract new scientists |
| | Effort | Require | | 19. | | | other disciplines (can this activity be grouped with |
| | 1. | | Substantial | | others | from (| different life science disciplines?) |
| | 2 | = | Moderate | | 1. | - | No, cannot be grouped |
| | ā | _ | Low | | 2 | - | Do not know at this time |
| | Define | d Sequ | ence (Clearly defined sequential path for scientific | | 3. | - | Behavior, Performance and Human Factors |
| | | gation | | | 4. | - | Regulatory Physiology |
| | 1. | | Yes | | 5. | - | Cardiopulmonary |
| | 2 | _ | No | | 6. | - | Environmental health |
| | Paralle | e/Alter | native Path (are parallel or alternative pathways | | 7. | - | Musculoskeletal |
| • | appro | | | | 8. | - | Neuroscience |
| | 1. | = | Yes | | Q | - | Radiation Health |
| | 2 | _ | No | | 10. | - | Cell and Developmental Biology |
| | _ | d-base | *** | | 11. | - | Plant Biology |
| • | X X | - | Ground-based research required | | 12 | - | Life Support |
| | Space | _ | | | | | |
| | x | _ | Spacelab would be used for research | | | | |
| | ÊDO | _ | Spacelab needed for Extended Duration Orbiter | | | | |
| | | _ | Program research | | | | |

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Table 9 Page 1

Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| | | What will the radiation environment be within the space vehicle and what factors influence the flux, energy, and linear energy transfer spectra of the radiation? | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events be improved? | What requirements should be placed on robotic an human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern is for both in- flight performance and residual health. (See Regulatory Physiology Discipline Science Plan 1991 for further discussion of immunological issues) | What is the effect of space flight on all microorganisms? | Is chromosomal integrity and behavior during division affected in microgravity? | Are microgravity-grown tissues and organs competent? | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | How is the effect of gravity (and microgravity) on cells influenced by magnetic fields and radiation? |
| | | What will the radiati space vehicle and v energy, and linear radiation? | How can protection cosmic rays and the events be improved | What requirement human missions Mars with respectimonated from Eigensteed from | What impact do physiological, and the susceptibility materials alone of for both in-flight (See Regulatory 1991 for further issues) | What is the effections of the microorganisms. | ls chromosomal division affecter | Are micrograv competent? | Are there unic radiation (or or microgravity this biological syst | How is the ef |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Paralle//Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

| A can crop plants produce sufficient edible biomass gat a strat-terrestrially to support human crews? The following constraints should be considered in studying this question: — Closed environments — Recycling — Limited space — Gravity effects — Phytoganic volatile compounds and other trace — Gravity effects — Phytoganic volatile compounds and other trace contaminants — Radiation — Radiation risk to humans in space? What provisions must be taken during the course of 10 2 3 2 1 probabilities of radiation risk to humans in space? What provisions must be taken during the course of 10 2 3 2 1 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? 4 Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with long-duration flights result in permanent reflex deficits? Of the various countermeasures available to combat adverse cardiovascular effects on long-and short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. What are the specific mechanisms underlying the orthostatic Myotolension observed after flight? What are the effective countermeasures for this? | 2 | 2 | | | | | | | | _ | | | | | ŀ | ļ | | | | | | | | | | | | | | |
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| Can crop plants produce sufficient edible biomass extra-terrestrially to support human crews? The following constraints should be considered in studying this question: — Closed environments — Beycling — Limited space — Gravity effects — Phytogenic volatile compounds and other trace contaminants — Radiation — Adventitious biota (microbial and other) — Adventitious biota (microbial and other) — Adventitious biota must be used to extrapolate probabilities of radiation risk to humans in space? What provisions must be taken during the course of 10 2 3 2 1 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with long-duration flights result in permanent reflex deficts on longand short-duration missions, which are most effective, when and how should they be applied, and short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. What are the specific mechanisms underlying the orthostatic hypotension observed after flight? What are the specific mechanisms underlying the porthostatic hypotension observed after flight? What are the effective countermeasures for this? | <u>ა</u> | ; () | ╦┪ | 5 | 3 | Critical Question | Quest# | ပ | _ | | 3 4 | LO. | 9 | 7 | œ | თ | 10 | Ξ | 12 | 13 | 14 | 151 | 161 | 7/1 | 8 | Group | ≩ | other | Disc | _ |
| extra-terrestrially to support human crews? The following constraints should be considered in studying this question: — Closed environments — Recycling — Limited space — Gravity effects — Phytogenic volatile compounds and other trace contaminants — Adventitious biota (microbial and other) — Adventitious biota (microbial and other) — Adventitious biota (microbial and other) 5 How can animal models be used to extrapolate probabilities of radiation risk to humans in space? What provisions must be taken during the course of 10 2 3 2 1 robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? Will the decrease in afferent input to the vestibular, proprioceptive and somato-sensory systems associated with long-duits? Will the various countermeasures available to combat adverse cardiovascular effects on longand short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, centrifugation, and exercise. What are the specific mechanisms underlying the centrifugation, and exercise. What are the specific mechanisms underlying the orthostatic hypotension observed after flight? What are the effective countermeasures for this? | | | | 4 | | Can crop plants produce sufficient edible biomass | 9a1 | | Г | | 2 | + | - | × | × | × | × | × | × | | Ť | | 6 | ╁ | 1 | 5 | = | | | |
| following constraints should be considered in studying this question: - Closed environments - Recycling - Limida space - Gravity effects - Gravity effects - Adventitious biota (microbial and other trace contaminants - Radiation - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Adventitious biota (microbial and other) - Multa provisions must be taken during the course of 10 2 3 2 1 | | | | | | extra-terrestrially to support human crews? The | | | | | | • | | <u> </u> | <u> </u> | <u> </u> | <u> </u> | ۲ | < | | | <u>'</u> | | | | | | | | |
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| 3a1 2 5 6 d, not he 3a2 2 1 3 | | | | _ | | result in permanent reflex deficits? | | - | _ | | _ | | | | | | | | | | | | | | - | | | | | |
| 9- d, not he 3a2 2 1 3 | | | _ | | | Of the various countermeasures available to | | , | | رح. | | 0 | ď | <u> </u> | × | <u> </u> | > | > | > | | | | | | | • | | | | |
| d, not he 3a2 2 1 3 is? | | | | | | combat adverse cardiovascular effects on long- | | _ | | | | <u> </u> | | <u> </u> | < | < | < | < | < | _ | | - | _ | | o _ | 4 | | | | |
| d, not he 3a2 2 1 3 is? | | | | | | and short-duration missions, which are most | | | | , | | | | | | | | | | | _ | - | | | | | | | | |
| not he 3a2 2 1 3 is? | | | _ | - | | effective, when and how should they be applied. | | | _ | _ | | | | | | - | | | | | | | | | | | | | | |
| he 3a2 2 1 3 | | | | | | and in what sequence? These include but are not | | | _ | | | | | | | | | | | | | | _ | _ | | | | | | |
| he 3a2 2 1 3 | | | | | | limited to LBNP, fluid anti-g rehydration. | | _ | _ | | | _ | | | | | | | | | _ | | | | - | | | | | |
| he 3a2 2 1 3 is? | | | | | | centrifugation, and exercise. | | | | | | | | | | | | | | | | | | | | | | | _ | |
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| What are the effective countermeasures for this? | | | | | | | | | | | _ | | <u> </u> | <u> </u> | < | < | < | | <u> </u> | _ | _ | _ | | | 1, | n | | | | |
| | 4 | 1 | | - | | What are the effective countermeasures for this? | | | | | | | | | | | | | | | | | | | | | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Paralle/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

8

Table 9 Page 3

Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

Table 9

| . ~ | μ | 14 | ৪ | C1 C2 C3 C4 C5 Critical Question | Quest# | C 7.1 | 2 | ၉ | 4 | 5 | 9 | 7 | 8 | ┡ | 0 11 | _ | 2 13 | 14 | 15 | 16 | 17 | 18 (| aroup | Group w/ other | Disc | |
|-----------|-------|----|---|--|--------------|-------|----------|--------------|---|----|---|---|----|----------|---------------|----------|------|----|--------------|--------------|-------------|--------------|-------|----------------|----------|---|
| | | ı | 1 | What are the adaptations and deteriorations associated with prolonged exposure to unusual atmospheric environments, including the impact of microgravity, and how can countermeasures be | 408 | 2 | - | ო | е | - | - | × | × | ~ | × | × | | | - | - | - | 1 2 | | | | |
| 4 | | | | | 5c8 | 2 2 | <u> </u> | - | | τ- | m | × | | <u>×</u> | <u>×</u> | <u>×</u> | | | | - | - | | 7 | | | |
| 4 | -+ | | | formation? Are stress and/or changes in stress required for continued structural integrity? What are the critical characteristics or components of normal daily tissue stress and | 509 | 2 | <u> </u> | - | - | - | ო | × | ^_ | × | <u>×</u> | | | | | - | | - | 3, 7 | | | |
| | | | | strain histories that regulate bone and connective tissue development, maintenance, and adaptation? How are these characteristics affected by microgravity? | | | <u> </u> | | | | | | | | | | | | | | | | | | | |
| 4 | ₹ | | | How are regional changes in bone and connective tissue related to regional changes in muscle tissue? | 5c10 | 2 2 | OI. | | | _ | ო | × | × | × | <u>×</u> × | | | | - | - | | - | 3, 7 | | | _ |
| 4 | - 4 | | | How are neuromuscular activation patterns and musculoskeletal mechanics altered during activity (including exercise) in microgravity compared to | 5011 | 2 | 0 | - | | | ო | × | × | × | × | | | | _ | - | - | - | 7, 3, | ω | | |
| <u></u> - | | | | Are there specific load histories that affect the macromolecular assembly of connective tissues? | 2 d 2 | 8 | 2 | - | | - | က | × | × | | × | × | | | - | | - | - | 7 | | | |
| 6 4 | 4 | | | What are sensory inputs and coordination of muscular outcomes organized for generation of posture and locomotion before, during, and after flight? | 662 | N | <u>е</u> | - | N | - | 2 | × | × | × | <u>×</u> × | <u>×</u> | | · | - | - | - | - | 7, 8 | | | |
| e | | | | What are the optimal countermeasures for motor readaptation to partial-g or 1-g after adaptation to microgravity? | 6b3 | 2 | 2 | _ | 2 | _0 | Ν | × | × | × | × | × | | | - | | - | - | 7, 8 | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Page 4

Table 9 Page

Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

Table

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|--|---|---|--------|----|-------------|--------------|-------------|-----|--------------|----------|----|-------------|--------------|-----|--------------|----------|--------------|--------------|--------------|------------------|----------|---------------------------------------|
| What are the j microgravity? — How do necaging relate to susceptibility to altered gravita altered gravita what is the rol distribution, co water/fluids in complex organiinfluence other influence other mechanisms? Is musculoskelifunction comprethey readapt up and functional scarefully are(spindles, (3) w (4) intervertebr | lŏn | What processes explain the altered perceptions of (initial and body position in microaravity) | 6c5 | | - | | | 2 | | | | - | <u>- ×</u> | v . | | 4 - | <u>-</u> - | <u> </u> | - S | Group 7, 8, 3 | w/ other | ier Disc |
| How ig respectively the property of the proper | o | oint effects of radiation and | 811113 | 8 | | - | - | _ 7 | ო | <u>×</u> | × | × | × | × | | | | | | თ | | |
| at it it it it it it it it it it it it it | A d ela tibi | How do neoplasms common to chronological aging relate to limitation of cell lifespan and susceptibility to abnormal growth regulation under altered gravitational fields? | | | | | | | | | | | | | | | | | | | | |
| ting the state of | s that trior fluid fluid sx o | ole of gravity in the regulation of the omposition, and pressure of a living systems from cells to lisms? How do these changes in homeostatic and regulatory | 8Vb2 | N | 0 | <u> </u> | N | N | m | × × | × | × | × | × | | - | | γ | - | 4 , | | |
| 8 <u>i</u> 8 | n cc n cc sada netic | function compromised during spaceflight and can they readapt upon return to Earth? The structure and functional systems that should be examined carefully are: (1) the postural miscles (2) miscles | 8VI1 | N | Г | | _ | ო | - | <u>×</u> | _× | × | × | × | - | _ | - | - | - | 3, 7, 4 | ω | |
| 2 | ss. (serve | spindles, (3) weight/load-bearing bones and joints, (4) intervertebral discs, (5) the architecture of the connective tissues of the body and (6) musculoskeletal innervation. | | ·· | | | | | | | | | | | | | | | | | | |
| £ \$ \$ | s th se c and stas | What is the role of fluid redistribution in the response of the musculoskeletal system to altered gravity and how does gravity impact the homeostasis of fluid compartments within tissues? | 8VI4 | 2 | <u> </u> | N | 0 | 7 | <u>×</u> | × | × | × | × | × | | <u> </u> | - | - | <u>√</u> | α | | · · · · · · · · · · · · · · · · · · · |
| # E 2 | 정 <u>-</u> 등 | What local changes occur in the musculoskeletal 8 system in response to changes in stresses, strains, and etrain rates? | 8VI10 | 2 | | | _ | ~ | <u>×</u> | × | × | × | × | × | | - | | - | | 60 | | |

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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| | | Are precursor cells of osteoblasts and osteocaffected by microgravity? | Do precursor bone cells respond to maturation stimuli in a microgravity environment as they on earth? | Do osteoblast require gravity to function normally? If developed in microgravity will tunction normally? | Are there changes in the processing of signals from the semicircular canals or otolith organs occur with adaptation? Do these changes take place within the vestibular nuclei, cerebellar | structures or other related brainstem and cortic structures? What is the time course of such changes and do they correlate with space motion sickness? | What are the neural (morphophysiological) and neuroendocrine bases for motion sickness? What changes in neurotransmitters, neuroendocrine, or neurohumoral release can be correlated with spac motion sickness? | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | and endc | n eq |
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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| and multisensory and models are most ons of angular and tion, somatosensory gorientation in a How do these gravity? | 7 | } ~. | | ? 6 <u>6</u> | 8Vb 8Vb | |
| 2 · 3 4 Does a change in vestibular input lead to changes in visual and auditory localization and multisensory spatial orientation? 2 · 3 4 What ground-based paradigms and models are most effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional environment? How do these interactions change in altered gravity? | | 5 What pharmacological agents should be develop and tested as prophylactic agents for low LET? | <u> </u> | What pharmacological agents should be developed and tested as prophylactic agents for low LET? How does gravity affect the regulation of metabolism,? Basal metabolic rate? Energy, metabolism, storage and substrate utilization? Body composition (fat and protein metabolism)? How does gravity interact with other environmental factors to control regulatory | nat pharmacological agents should be developed d tested as prophylactic agents for low LET? w does gravity affect the regulation of nabolism,? Basat metabolic rate? Energy, trabolism, storage and substrate utilization? dy composition (fat and protein metabolism)? w does gravity interact with other vironmental factors to control regulatory ysiology and behavior? | What pharmacological agents should be developed and tested as prophylactic agents for low LET? How does gravity affect the regulation of metabolism,? Basal metabolic rate? Energy, metabolism, storage and substrate utilization? Body composition (fat and protein metabolism)? How does gravity interact with other environmental factors to control regulatory physiology and behaviog? Do we need artificial gravity countermeasures to protect from physiological deconditioning of a mission to Mars? How should artificial gravity be applied in terms of g-load, rotation rate, and intermittent versus |
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| | | | | pulmonary adjustments to microgravity? What is the relationship, if any, between the pulmonary adjustments to space flight and those occurring in | | <u></u> | | | | | | | | | | - | | | | | | | | | | |
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| | 0 | | 4 | What is the role of specific hormones, pharmacologic agents, and growth factors in | 565 | 4 | о 8 | N | - | | က | × | | _ <u>×</u> _ | × | × | | | - | | | ν, | œ. | | | |
| | | | | regulating protein and gene expression in response to unloading? | , | | | | | | | | _ | - | | | | | | 7. | | - | | | | |
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| | | _ | | gravito-inertial frame of reference? What are the roles of the different regions of the cerebellum? | | | | | | | | | | | | | | *** | | | | | | | | |
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| | | - | - · | Vestibular processing that will account for alterations in eye movements in micronavity? | | | | | | | | | " | | | | | | | | | | | | | |
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| | | | _ | be used to predict motor behavior best in altered gravitational states? | | | | | | | | | | | | | | | - | · | | <u> </u> | ĵ | 2 | | |

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Table 9 F

Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| | | What are the subcellular mechanisms whereby h cells transduce acceleratory information, ampliit and bring about signal transmission? Is there | Tundamental mechanism that is true across the animal kingdom? What are the systemic, local, cellular, and subcellular mechanisms involved in adaptation altered gravity especially bineservation. | associated processes and cell-to-cell interactic What are the effects of space-induced endocrin changes on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation. | reproductive system, gastrointestinal system, energy metabolism)? What are the effects of microgravity on renal function, e.g. stone risk? Are the effects progressive? Are they reversible? Are there differences in filtration, reabsorption, secretion and excretion? |
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Table 9 Critical Questions 7

Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| | | I₽ | cells of protracted, chronic, low dose exposure to space radiation outside the Van Allen belts? What events in gametogenesis and early germ cell maturation are gravity sensitive, and how can | these results relate to the proliferation and differentiation of other individual cell types? | Can altered gravities affect fertilization, and these results inclicate more general mechanisms | membrane alteration in individual cells? | Which responses are transmitted maternally, and which are intrinsic to the developing embrvo? | a a | axis polarity and symmetries of the zygote? | Are there gravity effects that can terminate in changes of gene activation? | How does gravity affect compensatory | mechanisms (e.g. endocrine, organ, circulatory, | regenerative processes)? What is the interact with growth stages? What is gravity's effect | wound healing? | What is the role of gravity on thirst and feeding behaviors (appetite, taste preference, and | thresholds)? | What are the uses of microgravity for better | understanding of cardiovascular function on E | What are effects of weight bearing on | development? | What neuronal models can be used to understand | central processing and adaptation in area of gravitational states? |
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| characteristics of this converge? What are the obscious or elates and neural focial basis for perception or motion? 4. What are the psychophysical consistes and neural focial basis for perception or motion? 4. What are the concisial and subcortical neural focial basis for perception or motion? 4. What are the concisial and subcortical neural focial basis for perception or motion? 4. What are the concisial and subcortical neural focial basis for perception or ideal consistency and degeneration? 4. What are the biophysical and physiological motion in pasticity, and degeneration? 4. What are the biophysical and physiological motion in pasticity, and degeneration? 5. This is the continuous and the physiological motion in gravity directly, and degeneration of the physiology and pharmacollular structural/unctional mechanisms of versibilities in gravity directly, gellaz 4 if single cell sense changes in gravity directly, gellaz 4 if single cell sense changes in gravity as a three-dimensional continuum of perception and structural integrity? 5. 4. If single cells are an expossible for the cells: disturbed by gravity hart are particular structural integrity? 5. 4. If single cells are accordanced mensional continuum of gravity as a three-dimensional continuum of gravity as a three-dimensional continuum of gravity as a price-dimensional continuum of gravity as a price-gravity responsible for the cells: september is the cells and directly, what are the introductional mensions is the cessation of introconvective currents at microgravity responsible? 5. This is a separate of the cells of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the cells: september of the | | | | 4 | At what sites do signals from the different receptors involved in gaze, body orientation | | | | | - | N | × | × | × | × | | × | , | • | , | , | 7 | | 3, 8 | È | | |
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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| Q 4 4 4 | | If multicellular systems are necessary for gravity | | cell-cell communication are affected? Would the | increase sensitivity to indirect or environmentally | mediated effects (e.g., reduction of cell-cell and | cell- surface contact by dispersion of cells in | microgravity)? | | transduction of the stimulus of altered | gravitational force to a cellular response? By | what pathways is the perception of altered gravity | relayed intracellularly and/or extracellularly? | _ | | Are the gravity sensitive systems (i.e. | vestibular, proprioceptive, cardiovascular, | musculoskeletal) of young and adult animals | similarly sensitive to this stimulus in ontogeny? | 5 * What is the relationship between altered | hematocrit, renal function, and erythropoietin | levels in micro-, partial, and unit gravity? | r. | cell-mediated immune functions, nonspecific | immunity, or immune surveillance capabilities of | space crews in a manner that would expose them | to unacceptable medical risk while on a mission, | upon return to Earth, or as a consequence of | repeated mission exposure? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Cnincality
1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge
11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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| What are the time course and magnitude of space-flight-induced changes in the surface phenotypes (subpopulations), circulation patterns, or functional capacities of the cells of the immune system, including mucosal, humoral, cell-mediated and immune surveillance systems? — What factors cause or otherwise influence the consistently demonstrated post-flight reduction in blastogenic responsiveness to nonspecific mitogens (PHA, Con A, LPS)? — What are the dynamics of the leukocyte count during space flight with respect to: Induction of neutrophilia, lymphopenia, monocytopenis or eosinopenia — •numbers and functional capacity of natural killer (NK) cells — other changes in the WBC differential count, or the circulation/sequestration of immunologically active. | S 'What are the time course and mas space-flight-induced changes in the phenotypes (subpopulations), circlor functional capacities of the cell system, including mucosal, humo and immune surveillance systems— What factors cause or otherwiconsistently demonstrated post-flipblastogenic responsiveness to nor (PHA, Con A, LPS)? — What are the dynamics of the I during space flight with respect to a induction of neutrophilia, lymp monocytopenis or eosinopenia— numbers and functional capa killer (NK) cells — other changes in the WBC diffithe circulation/sequestration of in active | 'What are the time course and mas space-flight-induced changes in the phenotypes (subpopulations), circlor functional capacities of the cell system, including mucosal, humo and immune surveillance systems— What factors cause or otherwiconsistently demonstrated post-flip blastogenic responsiveness to nor (PHA, Con A, LPS)? — What are the dynamics of the I during space flight with respect to Induction of neutrophilia, lymp monocytopenis or eosinopenia — **numbers* and functional capa killer (NK) cells — other changes in the WBC diff the circulation/sequestration of in active. | atterns, mmune rediated ce the xion in nitogens count tural | 242 | 4 | | | | | | × | × | × | | × | × | | | _ | | 2 | | | | | |
| 5 What are the effects of space-flight-related factors, (e.g. bone demineralization and light spectrum) on nutritional requirements? | 4 | What are the effects of space-flight factors, (e.g. bone demineralization spectrum) on nutritional requiremen | | 2012 | 4 | | | | | | × | × | × | × | × | × | | | | | | | | | | |
| 4 5 Does a change in otolithic and proprioceptive activity function play a role in regulating calcium or antigravity muscle growth and function during development and aging and exposure to altered gravitational states? | * | Does a change in otolithic and propriactivity function play a role in regulor antigravity muscle growth and fudevelopment and aging and exposure gravitational states? | Eσ | 6b6 4 | | | | | | | × | × | × | × | × | × | | T | | Ψ- | | 4, | ^ | | | |
| 4 5 How do neural mechanisms regulate homeostatic processes? For example, what is the role of otolith input in regulating changes in cardiovascular function, such as orthostatic changes, heart rate, and baroreceptor responses | How do neural mechanisms regulate he processes? For example, what is the otolith input in regulating changes in cardiovascular function, such as orther changes, heart rate, and baroreceptor | How do neural mechanisms regulate h processes? For example, what is the otolith input in regulating changes in cardiovascular function, such as orther changes, heart rate, and baroreceptor | ç. | 6b8 4 | | | <u> </u> | | | | × | × | × | × | × | | | | | | | 4, | , | 10 | | |

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Page 14 Table 9

Table 9 Page 15

Table 9 Critical Qu

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| | | | | sickness? | | | _ | | | | _ | _ | | _; | > | | _ | | c | • | _ | ٠ ۲ | | | | |
| | | | 'n | How do plants adapt to microgravity? | 8lb7 | 4 | | | | _ | | | | <u> </u> | | | | _ | ų į | <u>, , , , , , , , , , , , , , , , , , , </u> | | 1 | | | | |
| | | | ĸ | 5 * What are the mechanisms by which transport | 9018 | 4 | | | | | × | <u>×</u> | × | × | × | × | | | N | Ν_ | | | | | | |
| | | | _ | systems are polarized in plants grown in space? | | | | | | | | | | | | - | _ | | | | | | ١ | r | 1 | |
| | | | LC. | . No single cells sense alterations in gravity | 811a4 | 4 | _ | | | | <u> </u> | × | × | × | × | | | _ | <u>~</u> | α_ | | 4, | , ', , | | _ | |
| | | | • | directly, in which cells are part of a gravisensing | | | | | | | | | | | | | | - | | | | | | | | |
| | | | | organ, or indirectly, in which the cells detect | | | | | | | | | | | | | | | | | | | | | | |
| | | | | indirect consequences of the presence or absence | | | | | | | - | | | | | | | _ | | | | | | | | |
| | | | | of inertial acceleration? | | | | | | | | | | | | _ | | | | | | | 1 | ١ | Ţ | |
| | | | LC. | * How do the following modifying factors affect | 811a5 | 4 | | | | | ^ | × × | × | | × | | _ | _ | <u>N</u> | <u>N</u> | | 4 <u>.</u> | o | : | _ | |
| | | | | gravity "sensing" at the cell level: cell size; | | | | | | | | | | | | | | _ | | | | | | | | |
| | | | | cellular dynamics: changes in cell shape; | | | | | | | | | | | | | | | | | | | | | | |
| | | | | prokaryotic versus eukaryotic cells; adaptive | | | | _ | | | | | | | | | | | | | | | | | | |
| | | | | yersus non-adaptive cells; circadian rhythms? | | | | | | | | | | | | _ | | _ | | | | | | | | |
| | | | ע | * Besearch indicates that resting/active cells are | 811b2 | 4 | | | | | <u></u> | × × | <u>×</u> | × | × | | | | | | - | 4 | | | | |
| | | | } | hot measurably affected by changes in gravity. | | | | | | | | | | | | | | | | | | | | | | |
| | | | | What is responsible for the difference in | | | | | | | | - | | | | | | | | | | | | | | |
| | | | | responsiveness between resting and active cells? | | | | | | | | | | | | | _ | | | | | | | | | |
| | | | Ľ | *How does the gravity stimulus affect cellular | 811b4 | 4 | | | | | | × × | <u>×</u> | × | × | | | _ | N | _ | _ | | | | | |
| | | _ | | responses following the binding of specific growth | | | | | | | | _ | | | | | | _ | | | | | | | | |
| | | | | factors to their cognate membrane receptorsas | | | | | | | | _ | | | | | | - | - | | | | | | | |
| | _ | | _ | an independent variable or a quantifier? What are | | | | - | | | | - | | | | | | | | | | | | | | |
| | | _ | | the contributions of the cytoskeleton, the | | | - | | | | | | | _ | | | | | | | | _ | | | | |
| | | | | intracellular pathways of chemically mediated | | | | | | | | | | | | | | | _ | | | | | | | |
| | | | | signal transfer, and the nuclear envelope/nuclear | | | | | | | | | | | | | | | | | | | | | | |
| | | | | matrix to functional response? | | _ | | | | | | | | | | | | | | | <u>_</u> | ` | | 0 | Ţ | |
| | | | 2 | * | 81166 | 4 | <u> </u> | | | | | ^ | <u>×</u> × | <u>×</u> | × | | | | <u> </u> | | | <u>+</u> | ń | | - | |
| | | | | multicellular systems affected by microgravity? | _ | | ┪ | ┥ | 4 |] | | ٦ | ┨ | \dashv | 4 | | 1 | 1 | 1 | 1 | + | ┨ | | | | |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality Table 9

| 4 | | ဗ | C1 C2 C3 C4 C5 Critical | tical | Question | ۲ | | Ŀ | F | Г | Γ | r | r | r | r | T | ŀ | ŀ | ŀ | ŀ | ļ | L | ļ | ļ | L | ļ | | | |
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| | 3 | | | - 1 | | 7 | #1senz | 5 | 2 | | 3 | 4 | 5 6 | , 7 | œ | တ | _ | 0 11 | _ | 2 | 3 14 | 4 15 | 16 | 17 | 18 | | Group w/ other | // ot | Disc |
| 5 * When do difference direct con | When do difference direct con | When do difference direct con | n do rence xt con | w, w, | 5 When do gravitational effects appear? Are there differences between responses that occur as a direct consequence of acute exposure to | | 811b7 | 4 | | · · · · · · · · · · · · · · · · · · · | | | | × | | × | × | × | × | | <u> </u> | - | 8 | 2 | - | 4, | 5, 7, | 80 | |
| microgravity a | microgra may refle mechanis | microgra may refl mechanis | ogra refl vani: | Z 8 Z | and responses at a later time, the operation of compensatory | ā | | | | | | | | | - | | | | | | | | | | | | | | |
| 5 * How car perturbir of other | + | How car perturbir of other | ther its | ے وہ <u>.</u> | How can gravity be used as a research tool in perturbing cell structure/function in the absence of other effectors? | | 811c2 | 4 | | | | | · | <u>×</u> | × | × | × | _ <u>×</u> | × | | | | N | N | | | | | |
| 5 * Which c | . Which c | Which c | å g | dev and | 5 * Which developmental mechanisms have evolved to be dependent on the 1-g gravity field and vector? | d to 81112 | 2 | 4 | | | | | | _× | × | × | _× | _ <u>×</u> _ | × | | | | | | _ | 4, | 7, 8 | | |
| 5 * Which gravity | * | Which gravity | ڃَڪ | orga fiel | * Which organ systems are dependent on the 1-g gravity field and vector? | 81113 | | 4 | | | | | <u></u> | × | × | _× | × | _× | | | | | | | - | 4, 5 | 5, 7, | œ | |
| 5 * Conside | | Conside phases | S G | erin, | മ് | or 81115 | | 4 | | | | | | _ <u>×</u> _ | <u>×</u> | × | × | × | × | | | | 2 | - | _ | | | | |
| progres gravity | progres gravity | progres gravity | es E | sin | w will Is that | | | | | | | | | | | | | | | | | | | | | | | | |
| represe — Ho | represe — Ho | represe Ho | 8 P | <u>5</u> ≥ | represent different species and phyla? — How will gravitational fields, particularly | | | | | | | | | | | | | | | | | | | | | | | | |
| microgr | microgr | microgr postura | <u>5</u> 6 | avit L co | microgravity, disturb the precise coordination and postural control required in mating? | and | | | | | | | | | | | | | | <u> </u> | | | | | * | | | | |
| - Will | - Will | ₩ | € | adı | - Will aquatic animals perceive and respond to | | | <u> </u> | | | | | | | | | | | | | | | | | | | | | - |
| gravity Those a | gravity Those a | gravity Those a | > ~ | as | gravity as do their terrestrial counterparts? Those animals which pursue different life and | | | | | | | | | | | | | | | | | | | | | | | | |
| in both | in both | in both | ⊊ | e - | in both environments may be particularly valuable | e le | | | | | | | | | | _ | | | | | | | | | | | | | |
| 5 * At what sta | *At what | At what | ᇘ | اخ. sta | 5 At what stage can we observe perturbations of | | | | | | | | | | _ | | | | | | | | | | | | | | |
| circadia | circadia | circadia | Ē | t | circadian rhythms, both temporally and with | | † | | | | | | | <u>×</u> | | <u>×</u> _ | × | <u>×</u> _ | <u>×</u> _ | | | _ | 2 | 7 | ` | э, 4 | | | _ |
| respect t | respect t | respect t | ا ہ | اه | respect to differentiation state? | | | | | | | | | | | | | | | | | | | _ | | | | | |

CI=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| ច | 8 | ප | 8 | છ | C1 C2 C3 C4 C5 Critical Question | #1sen | - | 2 | + | ٠, | ٥ | $\overline{\ }$ | | + | <u>, †</u> | + | | Ц. | 1 | <u>'</u> | _ | | | - | | | |
| <u> </u> | | | Ï | 5 * | puoc | 81119 | | | | | | × | | × | × | | | | _ | α_ | 2 | | CI. | | | | |
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| | | | | | demonstrated by the expression of selected target | | | | | | | | | | | | | | | | | | | | | | |
| _ | | | | | genes in transgenic mice with pre-determined | | | | | | | | | | | | | | | | | | | | | | |
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| | | | | ٠ * | nteractions be altered in | 811110 | | | | | | < | | | | | | | - | | | | | | • | | |
| | _ | | | | the space environment? | | _ | | | | | | | | | | | | _ | | | _ | | | | | |
| | | | | | Will hatching or parturition occur normally? | | - | | | | | | | | _ | | | | _ | | _ | | | | | | |
| | | | _ | | What will be the effects on lactation, suckling | | _ | _ | _ | | | | | | | | | | | | | | | | | | |
| | , | | | | and related parent- young bonding mechanisms? | - | _ | | | | | | | | | _ | | | | | | | | | | | |
| | | | | | — In the period of rapid post-natal growth, which | | | | | | | | | | | | | _ | _ | | | _ | | | | | |
| | | | | | systems are the most sensitive to altered gravity | | | _ | | | | | | | | | | _ | | | | | | | | | |
| | | | | | perturbations? | | | | | | | _ | | | | | | | | | | , | _ | | | | |
| | | | | , TO | 5 * What are the effects of gravity, in concert | 811111 4 | | | _ | | | × | | × | × | ─ × | × | | _ | N | | | | | | | |
| | | | | | particularly with life in closed ecosystems, on | | | | _ | | | _ | | | | _ | _ | _ | _ | | | | | | | | |
| | | | | | sexual maturation? | | | | | | | | | | | | _ | | | | | | | | (| | |
| | | | | ري. * | How does gravity produce responses in cultured | 81112 4 | | | | | | × | × | × | × | × | | | - | 2 | 2 | | 4, | ر. ک | xó. | מ | |
| | | | | | cells that mimic those seen in chronologically aged | | | | | | | | | | | | _ | | | | | | | | | | |
| | _ | | | | cells, those isolated from accelerated aging | | | | | | | | | | | | | | | _ | | _ | | | | | |
| | | | | | syndromes, and senescent cells in vitro? | | | - | _ | _ | | | | | | | _ | | | | | | | | | | |
| | | | | | Which de-limiters of lifespan have relevance to | | | | | | | _ | | | | | | | | | _ | | | | | | |
| | | | | | gravitational effects? | | _ | | | | | | | | : | | ; | | | | - 1 | _ | ٥ | Ç | | | |
| | | | | υ • | Is gravity a continuum in terms of | 81Va1 4 | _ | | | - | | × | | × | × | × | × | | | | | _ | o | 2 | | | |
| | | | | | stimulus/response? | | | | | | | | | | | | | | _ | | | | • | , | | | |
| | | | | Ŋ | 5 * What is the role of gravity in the evolution of | 81Va2 4 | | | _ | | | × | × | × | × | ×_ | × | | _ | | | _ | o` | 2 | | | |
| | | | | | animal gravity sensors? | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | _ | Ω | rties and fundamental | 81Va3 4 | | | _ | | | × | × | × | × | × | × | | | _ | _ | | 0 | | | | |
| | | | | | mechanisms that permit gravity sensors to adapt | | _ | | | | _ | | _ | | | | | | | | | | | | | | |
| | | | | | to an altered g-environment? | | _ | | | | | | | | | | | | | | | | | | | | |
| | | | | 2 | 5 * Will animals bred for many generations in | 8IVa4 4 | 4 | | | | | | | × | × | × | × | | _ | <u>. N</u> | | | 0 | | | | |
| | | | | | altered-g show phenotypically different gravity | | | _ | | | | | | | | | | | | | | | | | | | |
| | | | | | sensors? | | 4 | ┪ | ┪ | \dashv | 4 | 4 | 4 | ╛ | | |] | 1 | ┨ | \dashv | \dashv | \dashv | 4 | | l | | 1 |

C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality
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Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| • | Ques | 8IVc2 | 81Vc4 | 81Vc5 | 8IVd1 | 81Vd3 | 81Vd5 | 8IVe1 |
| | C1 C2 C3 C4 C5 Critical Question | *How do nerve fibers innervating gravity sensors convey information about linear acceleratory forces acting on the system? What is the basis of neural coding? | * Is there a fundamental principle of gravity sensor information processing that permits determination of the 3-dimensional (3-D) linear acceleratory environment of the body (in many invertebrates) and of the head in vertebrates? | * Is there a relationship between otoconial or statolith load and the acceleratory environment, and/or between this load and the neural substrate? | What are the principles of organization, and the inherent mechanisms, that underlie the adaptive capability of gravity sensors when animals are | placed in altered-g environments? Are there restrictive mechanisms in some species that prevent adaptation? (Could a bottom-dwelling flat fish, like a turbot, adapt to decreased gravity?) 5 Will animals bred in microgravity or hypergravity be able to adjust readily to Earth's gravitational environment, or will adaptation prove difficult because the animals are tuned to a gravitational | # p | * Does development of a gravity receptor in an |
| - | <u> </u> | ro • | <u>,</u> | 5 | | 5 | 'n | 2 + |
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C1

Critical Questions That Would Utilize Free Flyers Listed by Category and Criticality

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| i | | be those | for es onfine with | 1-g f senti sticity | Ç | space force? | S e | ween rmati olutio | n the |
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| | ritic | Would gravity sensors of animals bred in a sustained, altered gravitational environment be different structurally and functionally from those of animals bred on Earth? Would the changes be | Is there a critical time for exposure to 1-g for development of a gravity sensor with features typically associated with those of animals confined to Earth's 1-g environment? (Equal weight with 2 above.) | If there is a critical period for exposure to 1-g for normal gravity sensor development, is it essential to accomplish this to provide for future plasticity and for readaptability to Earth's 1-q? | Are there species differences in degree of susceptibility to a developmental change in an altered-q environment? | Would animals bred for many generations in sparetain their adaptive ability to an altered-g for Will this ability vary according to species? | What are the mechanisms that permit central adaptation to novel inputs from gravity sensors an altered-g environment? Does rewiring take place? | What is the importance of an interaction between gravity sensor input and other sensory information in total 3-D orientation, over time, of the organism? How does this change during evolution? | How does gravity affect interactions between circadian system and ultradian and infradian rhythms? |
| | C2 C3 C4 C5 Critical | 5 • Would gravity sensors of animals bred in a sustained, altered gravitational environmen different structurally and functionally from of animals bred on Earth? Would the change | 5 • Is there a critical time for exposure to 1-g for development of a gravity sensor with features typically associated with those of animals confit to Earth's 1-g environment? (Equal weight with above) | + - + + + + + + + + + + + + + + + + + + | 5 • Are there species differences in degree of susceptibility to a developmental change in altered-g environment? | Would animals bred for many generations in space retain their adaptive ability to an altered-g force? Will this ability vary according to species? | What are the mechanisms that permit central adaptation to novel inputs from gravity sensor an altered-g environment? Does rewiring take olace? | What is the importance of an interaction between gravity sensor input and other sensory information in total 3-D orientation, over time, of the organism? How does this change during evolution | 5 * How does gravity affect interactions between circadian system and ultradian and infradian rhythms? |
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| } | ┆┼ | ; † | ₹ | critical Question | | Quest# | ပ် | _ | 2 | 4 | ည | 9 | 7 | 00 | 6 | 0 | = = | 2 13 | 1 4 | 1 5 | 16 | 41 | 18 | Gran | Group w/ other | Jai Caic | Г |
| | | | ro. | 5 * How does gravity affect interactions between circadian system and other homeostatic mechanisms? | eractions between the homeostatic | 8Va3 | 4 | | - | | | | × | | × | × | | | ļ | <u> </u> | 2 | - 2 | | 4 | | | <u> </u> |
| | · · · · · · · · · · · · · · · · · · · | | S. | What is the role of gravity in the regulation and onset of reproductive cycles (vaginal opening, puberty, estrus cycles, fertilization, pregnancy | n the regulation and s (vaginal opening, tilization, pregnancy. | 8Vb11 | 4 | | | | | | × | × | <u>×</u> | <u>×</u> | × | • | | | | - | | 4, 10 | | | - |
| ··· | | | 22 | parturition, lactation, aging, life space, etc.)? 5 Are regulatory responses to an artificial 1-g environment in space equivalent to 1-g responses on Earth? | , life space, etc.)? 5 an artificial 1-g alent to 1-g responses | 8Vb13 | 4 | | | | | | × | × | × × | × | | | <u></u> | - | - | - | - | 4 | | | |
| | | | Ŋ | maintain normal regulatory function? If not, vis the minimum time? What are the optimal presentation characteristics of the G stimulus | sure necessary to function? If not, what are the optimal of the G stimulus? | 8Vb14 | 4 | | | | | | × | × | × | × | | | | _ | - | + | - | 4 | | | |
| 7 | | - | S. | 5 * Is the musculoskeletal cyto-architectural organization and responsiveness to physiological and mechanical stimuli altered by gravity? | -architectural ness to physiological red by gravity? | 8VI3 | 4 | | | | | | × | × × | × | × | × | | | - | + | | + | | | | |
| | | | ro. | 5 * Is the relationship between muscle and bone necessary for an integrated response to altered gravity or do the systems respond independently? | red | 8VI12 | 4 | | | | | | × | × | × | <u>×</u> | × | | | _ | - | + | | | | | |
| | | | ιΩ | 5 • Which mechanisms of adaptation of the musculoskeletal systems of rats, monkeys, and humans to altered gravity are similar and which mechanisms are different? | eys, and ind which | 8VI16 | 4 | | | | | | × | × | <u>×</u> | × | × | | | - | 8 | | | 7 | | | |
| | | | Ŋ | 5 • What is the degree of molecular complexity and evolution in circumstellar, interstellar, and protosolar environments? | its | 11a1 | 4 | <u> </u> | | | | | <u>×</u> | _ <u>×</u> | | × | × | | | 8 | N | | | | | | |

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TABLE 10

Critical Questions by Deliverables

CATEGORIES

- Environmental Health and Life Support Systems (EHLSS) are designed to protect the crew from inhospitable space and
- Countermeasure Systems (CS) are designed to continuously compensate for detrimental physiological and behavioral 2 manifestations of the space environment (e.g., microgravity, confined volume, radiation). They must provide acceptable mission performance and postflight recovery when: (1) EHLSS designed to provide habitable environmental conditions for the crew are not totally feasible because of mission design or inadequately of scientific or technological basis, or where cost and schedule are prohibitive; or (2) partial EHLSS failures occur, until appropriate remedial action is taken.
- Medical Care Systems (MCS), designed to handle illness and injuries based on probability of occurrence, restore crew 3 health for continued mission performance, or stabilize an ill or injured crewmember for rescue. MCS are also designed to handle illness or injuries resulting from failure, degradation, or maintenance of EHLSS or CS systems, but only temporarily until function is restored to the EHLSS.
- Science Specifically enabled by Moon and/or Mars Missions.
- Basic Research Not Directly Applicable to Moon and/or Mars Missions.
- Indicates primary category of application.

CRITICALITY

- Consensus that answer is required for Mars mission. (known effect and known problem for mission).* Criticality 1:
- Answers might be required, science basis to evaluate risk is not adequate.* Criticality 2:
- Criticality 3: Required for practical optimization of resources (or countermeasure effectiveness) and minimization of risk.
- Important science which is relevant to exploration mission. Criticality 4:
- *Crewmembers must be able to effectively perform mission tasks in transit vehicles and on planetary surfaces; and must recover in a reasonable time from any detrimental effects to lead normal, healthy lives upon return to earth.

| 1. | Sci | ence Readiness Levels |
|----|-----|---|
| | 1. | Only folklore of practitioners and anecdotal data available |
| | 2 | Basic scientific concept formulated |
| | 3. | Ground models developed, flight validation required |
| | 4. | Flight validation performed |
| | 5. | Countermeasures identified |
| | 6. | Countermeasures tested |
| | 7. | Operational requirements established |
| 2 | Tec | thnology Readiness Levels |
| | 1. | Technology need identified |
| | 2 | Technology and conceptual solution available |
| | 3. | Component and/or breadboard validation in laboratory environment exist |
| | 4. | Flight validation performed |
| | 5. | Systems/subsystem prototype demonstration in a relevant ground or space environment completed |
| | | Sustain protesting demonstrated in a speed provincement |

- System prototype demonstrated in a space environment Actual system completed and flight qualified through test and 7.
- Demonstration 8 Actual system "flight proven" through successful mission
- operations Schedule (information required by) 3
- Near term < 5 years Mid term 6-10 years Far term > 10 years
- Effort Required
 - Substantia
 - Moderate
 - Low
- 5 Defined Sequence (Clearly defined sequential path for scientific investigation exists)
 - Yes No
- Parallel/Alternative Path (are parallel or alternative pathways 6 appropriate)
- Nο
- Ground-based
 - Ground-based research required
- Spacelab
 - Spacelab would be used for research
 - Spacelab needed for Extended Duration Orbiter **EDO** Program research
- SSF
 - Space Station Freedom would be used X

- 10. Centrifuge
 - SSF Centrifuge Facility would be used
- Free Flyer
 - Free flyer biosatellite
- 12 Lunar Base
 - Lunar base would be used
- 13. Robotic Explorer
- Robotic explorer would be used
- Other Requirements
 - Requirement for flight resources other then those identified in 8-10
- Flight Validation Required
 - Flight validation required
 - Not required
- **Facilities Sufficient**
 - Current ground facilities (NASA Centers, Universities and provide industry) are sufficient.
 - Current ground facilities insufficient
- 17. Community Sufficient
 - There is a sufficient scientific community already
 - committed or recruitable
 - Scientific community is insufficient
- 18. **Attract New Community**
 - Activity will attract new scientists
 - Activity will not attract new scientists
- Group with other disciplines (can this activity be grouped with others from different life science disciplines?)
 - No, cannot be grouped
 - Do not know at this time
 - Behavior, Performance and Human Factors
 - Regulatory Physiology
 - Cardiopulmonary
 - Environmental health Musculoskeletal
 - 8. Neuroscience
 - Radiation Health
 - 9
 - 10. Cell and Developmental Biology
 - Plant Biology 11.
 - 12 Life Support

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Legend for Deliverable Identification Numbers on Table 10 Reference to Volume 1 Section II

| used as testbeds for medical protocols and countermeasures development. Human-Rated Ground-Based CELSS Testbed Will be used to develop and validate research and technologies required for an operational bioregenerative life support system and to address environmental, health, and safety issues. Life Sciences SSF Testbed Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles. Characterize deep space radiation environments Determine the human radiation dose limits for space missions (protons and GCR) Provide solar event warning capability Provide protection from radiation (protons and GCR) Data on deep space radiation environment from precursor missions and any other deep space miss Data on the radiation shielding characteristics of feasible spacecraft materials and regolith Provide criteria for design and operation of bioregenerative components of a life support system that, as a minimum, provides partial recycling of oxygen, water, carbon dioxide, and waste | <u> </u> | | Reference to volume i Section ii |
|--|----------|--------|---|
| energy transfer spectra of the radiation 11-1 | - | | |
| 11-1 Provide data necessary to utilize regolith as a raw material for bioregenerative life support identify potentially toxic materials | 1 | -1 | energy transfer spectra of the radiation |
| III-1 Identify potentially toxic materials Frovide data on sources of water and oxygen III-1 Identify potential sources of back contamination by biological materials Equip orbiters and rovers to study effects of radiation, microgravity, and magnetic fields on suitate organisms III-1 Equip orbiters and rovers to incorporate appropriate exobiology studies Develop sterilization technologies for vehicles landing on Mars Develop technologies and protocols for sterilizing, sealing, and monitoring samples returning to Ea Conduct risk analysis for development of policy regarding planetary contamination Data from robotic MSRO and MSVR mission required for EHLSS, CS, and MSC systems III-2 Experimental results from Exobiology Data for Planetary Protection Program Experimental results from Exobiology Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere III-3 I | 2 | 11-1 | |
| 11-1 Provide data on sources of water and oxygen Identity potential sources of back contamination by biological materials Equip orbiters and rovers to study effects of radiation, microgravity, and magnetic fields on suitation organisms III-1 Equip orbiters and rovers to incorporate appropriate exobiology studies III-1 Develop sterilization technologies for vehicles landing on Mars Develop technologies and protocols for sterilizing, seating, and monitoring samples returning to Eat Conduct risk analysis for development of policy regarding planetary contamination Data from robotic MSRO and MSVR mission required for EHLSS, CS, and MSC systems III-2 Data for Polanetary Protection Program Experimental results from Exobiology III-3 Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere Identity requirements and technology for food storage, processing, and preparation Verify life support system capability for EVA and EHA, and provide enhanced technologies Identity requirements and technology for real time monitoring systems for air, water, and surface quality III-3 Determine requirements for lighting, work-rest schedules, privacy, odor, etc.; and identify means design habitable facilities Provide basis for optimum design of human-machine interfaces Provide basis for optimum design of human-machine interfaces Provide basis for optimum design of human-machine interfaces Provide basis for medical protocols and countermeasures development. Human-Factors Stimulators Provide based callogs including transit vehicle simulators and planetary habitats simulators will tused as testbeds for medical protocols and countermeasures development. Life Sciences SSF Testbed Will be used to develop and validate research and technologies required for an operational bioregenerative life support system and to address environmental, health, and safety issues. Life Sciences SSF Testbed Will be used for validation of life support, medi | 3 | 11-1 | Provide data necessary to utilize regolith as a raw material for bioregenerative life support |
| lentify potential sources of back contamination by biological materials 11-1 | 4 | 11-1 | Identify potentially toxic materials |
| Equip orbiters and rovers to study effects of radiation, microgravity, and magnetic fields on suitation organisms 8 III-1 Equip orbiters and rovers to incorporate appropriate exobiology studies Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for vehicles landing on Mars Develop sterilization technologies for sterilizing, sealing, and monitoring samples returning to Ea Conduct risk analysis for development of policy regarding planetary contamination Data from robotic MSRO and MSVR mission required for EHLSS, CS, and MSC systems Data for Planetary Protection Program Experimental results from Exobiology Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere Identify requirements and technology for food storage, processing, and preparation Verify life support system capability for EVA and EHA, and provide enhanced technologies Identify requirements and technology for real time monitoring systems for air, water, and surface quality Determine requirements for lighting, work-rest schedules, privacy, odor, etc.; and identify means design habitable facilities Provide basis for optimum design of human-machine interfaces Verify sufficiency of expendable supplies and physico-chemical regenerative technologies for early missions Regular update and refinement of mission scenarios, planned crew activities, and design decisions Human-Rated Ground-Based CLESS Testbed Will be used for validation of life support, medical care and countermeasures under operational bioregenerative life support system and to address environmental, health, and safety issues. Life Sciences SSF Testbed Will be used | 5 | 11-1 | |
| organisms Equip orbiters and rovers to incorporate appropriate exobiology studies 11-1 10 11-1 11-1 11-1 12 11-2 13 11-2 13 11-2 13 11-2 13 11-2 13 11-2 13 11-2 14 11-2 15 11-3 | 6 | 11-1 | |
| 11-1 Develop sterilization technologies for vehicles landing on Mars Develop technologies and protocols for sterilizing, sealing, and monitoring samples returning to Ea Conduct risk analysis for development of policy regarding planetary contamination Data from robotic MSRO and MSVR mission required for EHLSS, CS, and MSC systems Data for Planetary Protection Program Experimental results from Exobiology Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere III-3 | 7 | -1 | organisms |
| 10 | 8 | 11-1 | |
| 11 1-1 Conduct risk analysis for development of policy regarding planetary contamination 1-2 1-3 11-2 Data from robotic MSRO and MSVR mission required for EHLSS, CS, and MSC systems Data for Planetary Protection Program 1-1 1-2 Experimental results from Exobiology Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere Identify requirements and technology for food storage, processing, and preparation Verify life support system capability for EVA and EHA, and provide enhanced technologies Identify requirements and technology for real time monitoring systems for air, water, and surface quality II-3 Determine requirements for lighting, work-rest schedules, privacy, odor, etc.; and identify means design habitable facilities Provide basis for optimum design of human-machine interfaces Verify sufficiency of expendable supplies and physico-chemical regenerative technologies for early missions Regular update and refinement of mission scenarios, planned crew activities, and design decisions Human Factors Stimulators Ground-based analogs including transit vehicle simulators and planetary habitats simulators will to used as testbeds for medical protocols and countermeasures development. Human-Rated Ground-Based CELSS Testbed Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles. Life Sciences SSF Testbed Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles. Characterize deep space radiation environments Determine the human radiation dose limits for space missions (protons and GCR) Provide solar event warning capability Provide protection from radiation (protons and GCR) Data on the radiation shielding characteristics of feasible spacecraft materials and regolith Provide criteria for design and operation of bioregenerative components of a life support system that, as | 9 | 11-1 | |
| 12 11-2 Data from robotic MSRO and MSVR mission required for EHLSS, CS, and MSC systems 14 11-2 Data for Planetary Protection Program 15 11-3 Experimental results from Exobiology 16 11-3 Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere 16 11-3 Identify requirements and technology for food storage, processing, and preparation 17 11-3 Verify life support system capability for EVA and EHA, and provide enhanced technologies 18 11-3 Identify requirements and technology for real time monitoring systems for air, water, and surface quality 19 11-3 Determine requirements for lighting, work-rest schedules, privacy, odor, etc.; and identify means design habitable facilities 20 11-4 Verify sufficiency of expendable supplies and physico-chemical regenerative technologies for early missions 21 11-4 Verify sufficiency of expendable supplies and physico-chemical regenerative technologies for early missions 21 11-4 Regular update and refinement of mission scenarios, planned crew activities, and design decisions 11-5 Human-Rated Ground-Based CELSS Testbed 11-6 Will be used to develop and validate research and technologies required for an operational bioregenerative life support system and to address environmental, health, and safety issues. 25 11-5 Life Sciences SSF Testbed Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles. 26 11-6 Characterize deep space radiation environments 29 11-7 Data on deep space radiation (protons and GCR) 29 11-7 Provide order over warning capability 29 11-7 Provide protection from radiation (protons and GCR) 30 11-7 Data on deep space radiation environment from precursor missions and any other deep space miss 31 11-7 Data on deep space radiation environment from precursor materials and regolith 20 11-8 Provide protection from radiation provides parti | 10 | 11-1 | |
| 13 II-2 Data for Planetary Protection Program Experimental results from Exobiology Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere Identify requirements and technology for food storage, processing, and preparation Verify life support system capability for EVA and EHA, and provide enhanced technologies III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-3 III-4 III-3 IIII-3 III-3 IIII-3 IIII-3 IIII-3 IIII-3 IIIIIIII | 11 | 11-1 | |
| 14 II-2 Experimental results from Exobiology Define acceptable human health and safety limits for quality and quantity of water, food, and atmosphere Identify requirements and technology for food storage, processing, and preparation Verify life support system capability for EVA and EHA, and provide enhanced technologies Identify requirements and technology for real time monitoring systems for air, water, and surface quality Determine requirements for lighting, work-rest schedules, privacy, odor, etc.; and identify means design habitable facilities Provide basis for optimum design of human-machine interfaces Provide basis for optimum design of human-machine interfaces Provide basis for optimum design of human-machine interfaces Regular update and refinement of mission scenarios, planned crew activities, and design decisions Regular update and refinement of mission scenarios, planned crew activities, and design decisions Regular update and refinement of mission scenarios, planned crew activities, and design decisions Human-Factors Stimulators Ground-based analogs including transit vehicle simulators and planetary habitats simulators will be used as testbeds for medical protocols and countermeasures development. Human-Rated Ground-Based CELSS Testbed Will be used to develop and validate research and technologies required for an operational bioregenerative life support system and to address environmental, health, and safety issues. Life Sciences SSF Testbed Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles. Provide protection from radiation environments Determine the human radiation dose limits for space missions (protons and GCR) Provide protection from radiation (protons and GCR) Data on deep space radiation environment from precursor missions and any other deep space miss Data on the radiation shielding characteristics of feasible spacecraft materials and regolith Provide criteria for design and operation of bioregenerative component | 12 | 11-2 | |
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| Verify life support system capability for EVA and EHA, and provide enhanced technologies Identify requirements and technology for real time monitoring systems for air, water, and surface quality 19 II-3 20 III-3 21 II-4 22 III-4 23 II-5 24 II-5 25 II-5 26 II-6 27 II-6 28 II-6 29 II-7 20 II-7 20 II-7 20 II-7 20 II-7 20 II-7 20 II-7 20 II-8 20 II-8 20 II-9 20 II-9 20 II-9 20 II-9 21 II-4 22 II-9 23 II-9 24 II-9 25 II-9 26 II-9 27 II-9 28 II-9 29 II-9 20 II-9 20 II-9 20 II-9 20 II-9 20 II-9 20 II-9 21 II-9 22 II-9 23 II-9 24 II-9 25 II-9 26 II-9 27 II-9 28 II-9 29 II-9 29 II-9 20 II-9 20 II-9 20 II-9 20 II-9 20 II-9 20 II-9 21 II-9 22 II-9 23 II-9 24 II-9 25 II-9 26 II-9 27 II-9 28 II-9 29 II-9 29 II-9 20 | | | atmosphere |
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| missions Regular update and refinement of mission scenarios, planned crew activities, and design decisions Human Factors Stimulators Ground-based analogs including transit vehicle simulators and planetary habitats simulators will be used as testbeds for medical protocols and countermeasures development. Human-Rated Ground-Based CELSS Testbed Will be used to develop and validate research and technologies required for an operational bioregenerative life support system and to address environmental, health, and safety issues. Life Sciences SSF Testbed Will be used for validation of life support, medical care and countermeasures under operational conditions for transit vehicles. Characterize deep space radiation environments Determine the human radiation dose limits for space missions (protons and GCR) Provide solar event warning capability Provide protection from radiation (protons and GCR) Data on deep space radiation environment from precursor missions and any other deep space miss Data on the radiation shielding characteristics of feasible spacecraft materials and regolith Provide criteria for design and operation of bioregenerative components of a life support system that, as a minimum, provides partial recycling of oxygen, water, carbon dioxide, and waste Provide trade-off analysis comparing expendable, PC, integrated PC-bioregenerative, and | 20 | 11-3 | |
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| 32 II-8 Provide criteria for design and operation of bioregenerative components of a life support system that, as a minimum, provides partial recycling of oxygen, water, carbon dioxide, and waste 33 II-8 Provide trade-off analysis comparing expendable, PC, integrated PC-bioregenerative, and | 30 | 11-7 | Data on deep space radiation environment from precursor missions and any other deep space missions |
| that, as a minimum, provides partial recycling of oxygen, water, carbon dioxide, and waste 33 II-8 Provide trade-off analysis comparing expendable, PC, integrated PC-bioregenerative, and | 31 | 11-7 | Data on the radiation shielding characteristics of feasible spacecraft materials and regolith |
| 33 II-8 Provide trade-off analysis comparing expendable, PC, integrated PC-bioregenerative, and predominantly bioregenerative life support systems | 32 | 2 11-8 | that, as a minimum, provides partial recycling of oxygen, water, carbon dioxide, and waste |
| | 33 | 3 11-8 | predominantly bioregenerative life support systems |
| 34 II-8 Provide criteria for design and operation of a predominantly bioregenerative life support system | 34 | 4 11-8 | Provide criteria for design and operation of a predominantly bioregenerative life support system |

Legend for Deliverable Identification Numbers on Table 10 Reference to Volume 1 Section II

| Ita | | Table | Title |
|----------|------|-------|---|
| \vdash | - | | |
| 3 | 3 5 | 11-8 | Identify storage, processing, and preparation technologies for food produced in bioregenerative life support systems |
| 3 | 6 | 11-8 | Provide mathematical models for simulation, design, and operation |
| 3 | 7 | 11-8 | Provide technologies to use regolith as a resource in bioregenerative life support systems |
|] 3 | 8 | 11-8 | Establish nutritional and behavioral requirements for fresh food on long duration missions |
| 3 | 9 | 11-9 | Data on oxygen and water availability |
| 4 | 0 | 11-9 | Data on composition and characteristics of regolith |
| 4 | 1 | 11-9 | Data on radiation environment throughout mission scenario |
| | | II-10 | Provide the criteria for design and operation of CS (e.g., exercise, dietary, pharmacological, mechanical, physiological, training) for human adaptations (e.g., musculoskeletal, cardiovascular, physiological, neurological, and cellular) to microgravity |
| 1 | | | Provide the criteria for design and operation of CS for human adaptations to the Moon (0.16g) |
| l | - 1 | | Provide the criteria for design and operation of CS for human adaptations to the Mars (0.38g) |
| 4 | 5 1 | 11-10 | Provide trade-off studies for CS alternatives (including human centrifuges) |
| 4 | 6 1 | 11-10 | Provide criteria for design and operations of CS for readaptation, to Farth |
| 4 | 7 | 11-11 | Mission scenarios, including a timeline with duration of exposure to the various levels of hypogravity and a description of the expected activity (including EVA and EHA) during the increments |
| 4 | 8 | | Provide the criteria for design and operation of countermeasures for human responses to space vehicle and planetary base environments not specifically related to hypogravity (e.g. atmosphere, toxins, food quality, confined volume, light, restricted human interaction, privacy, recreational activities, esthetic diversity, and stress) |
| 4 ! | 9 1 | 1-12 | Provide criteria and protocols for crew selection, training, and scheduling to mitigate effects of space flight environmental factors |
| 5 (| ı c | 1-12 | Provide trade-off studies for countermeasure alternatives |
| 5 | 111 | 1-13 | Mission scenarios including timelines for activities including EVA and EHA |
| 52 | ² ' | -14 | Provide the criteria necessary to design and equip health maintenance facilities (including EVA and EHA risks) for Moon and Mars transit vehicles and bases |
| | 1 | | Develop preventive medicine, and monitoring, therapy and treatment protocols for exploration missions |
| 54 | Ш | 1-14 | Provide telemedicine capability for medical contingencies |
| 5 5 | 5 11 | 1-14 | Provide medical criteria for crew selection |
| 56 | 111 | 1-14 | Develop the medical training protocols for exploration mission crews |
| 57 | TIII | -14 | Provide protocols for post mission health monitoring and care |
| 58 | Ш | -15 | Mission scenarios including timelines and activities such as EVA and EHA. |
| 59 | 111 | -16 | Provide science and technology requirements necessary to design the laboratory for Moon base |
| 60 | | 1-16 | acilities . |
| 61 | 11 | -16 | Provide science and technology requirements necessary to design laboratory for Mars base |
| 62 | 11 | -16 | Provide research proposals for SSF, Moon, Mars transit vehicle, and Mars base laboratories |

Table 10

Critical Questions Listed by Deliverable from Volume 1 Section II

| <u> </u> | 2 | 5 | ~ | | - | - | |
|-----------------|--|---|--|---|--|---|--|
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| | For a given mission, what are the fluxes of GCR in interplanetary space as a function of particle and solar cycle? | What is the trapped radiation flux as time, magnetic field coordinates and coordinates? | What are the doses related to heavy space? | What provisions must be taken during the course of robotic and human exploration to protect the Earth from harm caused by the importation of biological materials from Mars (back contamination)? | What requirements should be placed on robotic an human missions (orbiters and landers) to protect Mars with respect to biological contamination imported from Earth (forward contamination)? | What are the effects of pressure and gas composition in space flight and during EVA on chances on fluid and electrolyte regulation? | What impact do space flight-induced biological, physiological, and immunological changes have on the susceptibility of crewmembers to toxic materials alone or in combination? The concern it for both in- flight performance and residual health (See Regulatory Physiology Discipline Science Plance or further discussion of immunological |
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Section Critical Questions Listed by Deliverable from Volume 1

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| | Ę | What are the effects of all potential atmospheric components, including contaminants and factors on physical and psychological well-being and crew performance? | What types and surface area of plants will be required to meet the production rate demands for revitalized air and what environmental conditions do these plants require? | Can the physico-chemical regenerative technologies and processes required for a Mars mission life support system function in the space environment? Consider: — Maintenance of liquid-gas interfaces (e.g., for nutrient delivery) — Transfers and separations of liquids, solids, a gases — Combustion What is the composition of air, water, and spacecraft systems and how is it monitored to assure crew health safety and performance? | What are the specific nutritional requirements for humans in space? This question should consider at least the following: — Caloric requirements Will the nutritional requirements of the crew change and require modified diets over time of flight — Fluid requirements — Distribution of the macro nutrients (protein, carbohydrate, lipid) — Fiber and micronutrient requirements |
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| Ca | 18 | what priority order should they be evaluated? Some criteria include: — Safety and freedom from toxic substances and infectious agents — How will the crew respond to diet on a Mars mission — Nutrient and attribute balance — Familiarity/cultural experience — Taste/texture/color/shape — Flexibility in preparation methods — Cooking (time, complexity, etc.) — Seasoning (diversity of options) — Compatibility with other menu items — Variety What food groups fulfill these requirements? — How can the biomass candidates be used or modified to achieve the desired requirements? | How stable in storage are foods considered for Mars mission and how can storage stability in space be increased? — What are the safety and quality considerations of storage? — What processes are feasible to use in a CELSS? — Are additives needed? If so, which ones? — What are the storage/inventory requirements? — For what types of foods will storage be unnecessary? — Is there a need for packaging? If so, which products will require it? |
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| = | What food processing and storage technologies will need to be developed for space application? — How will existing and new processing and storage techniques perform in the constraints of a CELSS environment? — What differences are there in product development for space compared to land-based activities? — What are the influences of processing, cooking, and serving on — nutrient and attribute stability? — How can processing and cooking techniques be used to modify and improve the acceptability of foods offered the crew? | Can safe and sufficient supplies of water and air be provided for the trip/stay to/at Mars? Do current expendable systems exist to provide safe and sufficient supplies of water and air for the Mars mission? | Can safe and sufficient supplies of food be provided 911c for the trip/stay to/at Mars? Do current expendable systems exist to provide safe and sufficient supplies of food for the Mars mission? | Do systems exist to provide EVA required for Mars transit? | Do systems exist to provide EVA/EHA capabilities required for Mars surface exploration? | Do automated real-time systems air quality/toxicology for Mars |
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Section II

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| | What are the requirements for adequate quality of life as they relate to food, clothing, hygiene, vibroacoustics, lighting, and other personal needs (privacy, recreation) in spacecraft and habitats? | What are the optimal designs for living/working areas in spacecraft/habitats to maximize morale and performance? | What are the most effective schedules for work, rest and recreation, exercise and sleep for enhancing human performance and adaptation during long-duration exposure to space? | How is workload optimized for various space explorations? | What are the criteria for evaluating individual and crew performance and productivity during space missions of various durations? | What minimally intrusive hardware and capabilities are best suited for obtaining performance data in flight? | How do circadian rhythm cycles and sleep influence 1f11 performance and interact with the space environment to affect ability to accomplish mission goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity? |
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Table 10

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| C1 C2 C3 C4 C5 Critical Question | What are the effects of the space environment on sleep, sleep cycles, or the generation, expression (period, phase, amplitude and/or waveform), and entrainment of metabolic, endocrine, reproductive, and/or behavioral circadian rhythms? Of these effects, which result from altered gravity and which result from other environmental factors? | What are the optimal environmental conditions for ensuring synchronization of circadian rhythms in space, and what are the most appropriate work-rest schedules for ensuring optimal health and performance? | What environmental conditions of space flight influence temperature regulation? | What are the appropriate light wave length cycles to maximize vitamin D production? | What are the factors involved in integrating automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and countermeasures for particular missions? | What factors should be considered (e.g. maintainability, reliability, operator discretion) when allocating functions between humans and machines? |
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Critical Questions Listed by Deliverable from Volume 1 Section II

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| | Critical Question | What are the requirements for formatting, distributing, managing, accessing, updating, and presentation of information for optimal individual and crew performance? What are the requirements for crew input to the data management system? | What are the human factors issues in teleoperation? | What are the anthropometric requirements for work stations to accommodate individual team members to maximize performance? | How can artificial intelligence systems be used to support human decision-making in long-duration space flight? | What are the mission specific design and protocol requirements for telecommunications to optimize crew performance? | What are the cross sections and yields for nuclear interactions of HZE particles in tissue and shielding materials? | How can the wealth of knowledge existing for energy deposition in gaseous media be extended to the liquid phase applicable to most living cells? | | How is physical energy deposition related to biological effect? | |
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| C3 C4 C5 Critical Question | = 8 | | What mechanisms are involved in modulating radiation damage at the molecular level (repair, errors in repair, gene amplification, etc.)? | How can molecular mechanisms of radiation damage be used to understand effects in whole cells? | What is the probability of initiating neoplastic cell transformation or other steps leading to a cancerous cell? | How do cellular repair mechanisms modulate damage produced by energetic charged particles? | How can the radiation effects on cells in culture be related to radiation effects in "normal" cells and tissues? | How can cellular mechanisms of radiation damage be used to understand effects in whole organisms? | How can animal models be used to extrapolate probabilities of radiation risk to humans in space? | What is the relative biological effectiveness of different types of radiation for the relevant endpoints such as cancer; cataracts? |
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Table 10

Deliverable from Volume 1 Section II Critical Questions Listed by

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| What is the age dependence of relevant radiation effects in animals (cancer, cataractogenesis, life shortening, etc.)? | | | | | What is the age dependence of releve effects in animals (cancer, cataracto shortening, etc.)? | | 715 2 | 2 | | | | | , <u>£</u> | | | | = | 2 | 2 | 4 | 2 | 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | | _ _ |
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| What is the probability of cancer as dose, dose rate, radiation quality, ge exposure, and time after exposure? effect of GCR at different stages of t carcinogenesis process? | What is the probability of cancer as dose, dose rate, radiation quality, ge exposure, and time after exposure? effect of GCR at different stages of carcinogenesis process? | What is the probability of cancer as dose, dose rate, radiation quality, ge exposure, and time after exposure? effect of GCR at different stages of carcinogenesis process? | What is the probability of cancer as dose, dose rate, radiation quality, ge exposure, and time after exposure? effect of GCR at different stages of carcinogenesis process? | What is the probability of cancer as dose, dose rate, radiation quality, ge exposure, and time after exposure? effect of GCR at different stages of carcinogenesis process? | ν Ö . — | i a function of 7g gender, age at What is the the | 793 1 | | 4 | - | - | - | ž × | × | | | | | | | N | 2 | † | |
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| ic al | 5 What is the probability for genetic al developmental detriment incurred as of radiation exposure in space? | What is the probability for genetic al developmental detriment incurred as of radiation exposure in space? | What is the probability for genetic al developmental detriment incurred as of radiation exposure in space? | What is the probability for genetic al developmental detriment incurred as of radiation exposure in space? | I # | consequence | 7g5 3 | | 2 4 | - | - | - | × E | × | × | × | | | | | 2 | 1 - | + | |

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| CA C5 Critical Question | the sufficient of the sufficie | What are the joint effects of radiation and microgravity? — How do neoplasms common to chronological aging relate to limitation of cell lifespan and susceptibility to abnormal growth regulation under aftered gravitational fields? | What is the solar cycle dependence of space radiation? | What are the maximum flux, the integrated fluence, and the probability of large Solar Particle Events (SPE) during any mission? | What are the factors that determine radiation flux of solar flares? |
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| | What will the radiation environment be within the space vehicle and what factors influence the flux, energy, and linear energy transfer spectra of the radiation? | How can protection against the effects of galactic cosmic rays and the proton radiation of solar events be improved? | | | a function | 1 | | | 70/ 12 | | ies |
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| - | What will the radiation environment space vehicle and what factors influenergy, and linear energy transfer radiation? | How can protection against the effecosmic rays and the proton radiation events be improved? | What are the angular distributions of interaction products? | What are the particle interaction products? | a ra | # to | 鲁 | s? | e te | ₹ \$ | the sis |
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| | Wh spa ene | Hov Cosi | Wh ₂ | What are the particle multiplicities interaction products? | How is a radiation field transformed of depth in different materials? | What are the optimal ways of calculating the transport of radiation through materials? | What is the precise energy deposition of heavy ions? | What are the yields and energy spectra | Are there terrestrial (1 g) human, animal and/or computer models that simulate or reproduce the effects of space flight/microgravity with regard to the immune system in space? | What are the thresholds required for have an effect? | |
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| Critical Question | Can plants successfully reproduce through more than one generation in space? | behavior during cell | Is cell, tissue, or organ differentiation affected in microgravity? | What effect does microgravity have on embryogenesis and the ensuing stages of the life cycle of plants from maturity to flowering and senescence? | Are microgravity-grown tissues and organs competent? | Are the growth rates of higher plants or single cells affected by microgravity? | Are there unique interactions between space radiation (or other environmental factors) and microgravity that affect the development of biological systems in space? | Are anabolic and catabolic pathways and the photosynthetic apparatus and pathway altered in microgravity? | What effect does microgravity have on the synthesis of storage and support polymers? | 1 00 | What are the effects of the space environment on long distance transport of water and on transpiration? |
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Table 10

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| C4 C5 Critical Question | How is the effect of gravity (and microgravity) on cells influenced by magnetic fields and radiation? | Can crop plants produce sufficient edible biomass extra-terrestrially to support human crews? The following constraints should be considered in studying this question: — Closed environments — Recycling — Limited space — Gravity effects — Phytogenic volatile compounds and other trace contaminants — Radiation — Adventitious biota (microbial and other) | What conditions are required to optimize the food generating and water recycling capacity of crop plants? The following factors represent the minimum that should be considered in studying this question: — Light quantity, quality, periodicity, gas composition and density — Root environment: substrate, nutrients, volume, temperature, etc. — Aerial environment: gas composition and pressure, temperature, planting density, etc. | What are the effects of adventitious biota (microbial and other) over long periods in a CELSS? | What robotic and automated procedures should be developed for planting, growing, and harvesting of crop plants? |
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Table 10

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Critical Questions Listed by Deliverable from Volume 1 Section II Table 10

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| Critical Question | How can molecular genetic technology, including germplasm screening, be used to develop crop cultivars better fit for CELSS use in space? (for example) — Improve nutrient quality and bioavailability — Reduce natural toxicants — Optimize plant architecture | What is the potential for using the following alternative food sources in a CELSS? — Animals (aquatic and terrestrial, vertebrate and invertebrate) — Algae — Fungi — Non-traditional higher plants — Tissue-cultured cells — Synthetics | Can edible foods and/or ingredients be derived from non-edible plant wastes? — What are the crop plant-specific limits of this capability? | How will non-recyclable materials be minimized in a CELSS program? | How do the above nutritional questions apply to CELSS produced foods, used either as a nearly complete diet or as a supplement to stored food? | What are the processing requirements necessary to handle human wastes? What are the health and safety requirements for the waste treatment subsystem? |
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| 11. | What are the processing requirements necessary to convert metabolic wastes into nutrients suitab for plant growth? | What will be the limits of the composition of the processed waste streams with regard to the following parameters: — Organic an inorganic materials — Potentially toxic materials — Water content? | What currently available waste treatment/nutrient regeneration technologies can be adapted to a CELSS use, and what technologies will need to be developed for space application? (Note question 16.8) | To what extent will micro-organisms physico-chemical waste processor prissue of performance degradation? | What are the production rates and chemical compositions of the different waste stream are to be processed in a CELSS? | What can be done about food packaging, crop selection, etc., to minimize the amount of m that ends up in the waste streams? | Can plant transpiration water qualify as potable and hygiene water? If not, what currently available water treatment technologies can be adapted to polish transpiration water in a CELSS, and what technologies will need to be developed for space application? |
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Critical Questions Listed by Deliverable from Volume 1 Section II Table 10

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| Cal Cal Cal Critical Question | the best technologies for recycling the quired for a Mars mission to acceptable and hygiene levels? | can be used to meet for potable and pes and numbers of what environmental require? | What currently available water treatment technologies can be adapted to recycling the various grades of water (hygiene, wash, etc.) in a CELSS and what technologies will need to be developed for space application? | ts for potable and sider: urfaces | What will be the acceptability thresholds for revitalized air in an operational CELSS? | What currently available air treatment technologies can be adapted to a CELSS use, and what technologies will need to be developed for space application? |
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| C1 C2 C3 C4 C5 Critical Question | What circlanian | and control of the known or suspected possible causes of life support system instability? Consider: - Pests or pathogens (disease) SMACS - Toxicants produced by humans, by processing procedures, or by the plants themselves - Atmosphere leakage - Perturbations in environmental controls - Microgravity - Unarticipated ecological interactions - Scheduled or unscheduled system or mission events - Failure of microbial cultures in algal fermentation systems - Food variety | What are the requirements for CELSS system design and operation to achieve safe and reliable operation? Address the following: — Subsystem redundancy - Interaction with Chemical - Physical regeneration — System modeling and behavior — Alternative strategies for system monitoring and control — Failure of a subsystem | Is a CELSS, because it operates within a limited volume and intense dynamics, subject to unknown or poorly characterized instabilities, such as chaotic behavior? |
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| = | What are the thresholds of system and system safety and reliability (can these be extended in an integraystem? | What are the power requirements and Is and volume for an operational CELSS? | What robotic and automated proced developed for control, monitoring, | What sensors are required for automation of CELSS? | What is the productivity, transpiration, and dry matter partitioning of plants at less than 1xg (micro-, 15%, and 38% gravity)? | What is the morphology and reproductive capability of plants at less than 1xg (micro-, 15% and 38% gravity)? Will this modify crop selection criteria for space bases? | What countermeasures can be utilized if productivity or reproduction is significantly decreased? | What are the effects of the space microbial interactions with space humans? | Can wastes be successfully disposed of on a Mars mission without impacting planetary protection? | Do regenerative systems exist to sufficient supplies of food for the |
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Table 10

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| Delive C1 C2 C3 C4 C5 Critical Question | O postura of | safety/quality for Mars mission? | Can proposed food processing techniques be modified to work effectively at reduced gravity? | ا ہ ⊏ | What are the behavioral correlates of physiological 1e1 changes induced by the space environment? | What are the effects of living in the space flight environment on cognitive functions (including attention, memory, information processing and decision-making) and on work capacity? | How do the fundamental behavioral processes of perception and sensation, learning and cognition, and motor skills change in space? What is the time course of adaptation? | Does the well documented decrease in red blood cell mass termed "anemia of space flight" represent a normal microgravity-associated adaptive process (self-limiting) or a transient response (self-correcting) to changes brought about by various space-flight-related stimuli (stressors)? |
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Critical Questions Listed by Deliverable from Volume 1 Section

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| ۲ | | Is the basal metabolic rate and metabolic efficiency 2e1 altered during extended space flight? Are there changes in energy metabolism and storage in space, especially in substrate utilization? | | | |
| | What is the most effective way to restore red cell mass during simulated and actual microgravity? Should red cell mass be restored during space flight? Are these acute or chronic changes and are they of sufficient magnitude or duration to pose an unacceptable medical risk and warrant the development of countermeasures (prophylactic or therapeutic)? Formulate mathematical and computer models of tissue adaptation and cellular transient response to altered load histories? | Is the basal metabolic rate and metabolic efficier altered during extended space flight? Are there changes in energy metabolism and storage in space, especially in substrate utilization? | cell and nutrient utritional | What are the optimal noninvasive microanalytical methods and techniques for use during space flight to monitor nutritional status? | What are the mechanisms underlying the negative nitrogen balance and changes in lean body mass incurred during space flight? What are the possible interventions, including dietary atterations in proteins and amino acids? |
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| | What is the most effective way to restore recmass during simulated and actual microgravit Should red cell mass be restored during space flight? Are these acute or chronic changes are they of sufficient magnitude or duration to post unacceptable medical risk and warrant the development of countermeasures (prophylactitherapeutic)? Formulate mathematical and computer models of tissue adaptation and cell transient response to altered load histories? | Is the basal metabolic rate and maltered during extended space flig changes in energy metabolism and space, especially in substrate uti | What are the effect of changes in cell and turnover during space flight on nutritional requirements? | What are the optimal noninvasive methods and techniques for use do monitor nutritional status? | What are the mechanisms underlying the ne nitrogen balance and changes in lean body mincurred during space flight? What are the possible interventions, including dietary attentions in proteins and amino acids? |
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11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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| C1 C2 C3 C4 C5 Critical Question | Do the effects of space flight require added supplements of vitamins, minerals, or other nutrients? What is the safe range of exogenous vitamin intake for long-term space flight? Are nutritional requirements modified by transient digestive disturbances, such as the anorexia, nausea, and vomiting associated with space sickness? | What is the time course and nature of body composition change due to space flight? Do changes in body composition (age and gender) have an effect on crew health and performance? | Does space flight after gastrointestinal function, including the absorption of essential nutrients and the functioning of gut flora? What are the effects of space flight on liver function? Are the effects progressive? Are they reversible? | What are the time course and magnitude of fluid shifts and changes in fluid compartment volumes during acclimatization to hypogravity and during return to 1 g after flight? | What are the fluid and electrolyte regulating mechanisms underlying the cardiovascular responses to microgravity? | What are the mechanisms for the chronic adaptive shifts in fluid and electrolytes during space flight? How does the new steady state affect the body's ability to respond to heat stress, electrolyte loading, EVA, and countermeasures? |
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1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge 11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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| | Critical Question | 9.4 9.6 ive ive | What are the best methods to accurately measure fluid loss, fluid intake, plasma volume, extracellular fluid, total body water, and interstitial volume in space flight? | What are the effects of circadian rhythm changes in space flight on the responsiveness of the fluid | What are the roles of renal blood supply and renal electrolyte handling in extracellular fluid volume | What are the effects of space flight and/or EVA on | What are the effects of prescribed | countermeasures on thermoregulation? Of the various countermeasures available to combat adverse cardiovascular effects on longand short-duration missions, which are most effective, when and how should they be applied, and in what sequence? These include but are not limited to LBNP, fluid anti-g rehydration, | centrifugation, and exercise. What are the specific mechanisms underlying the orthostatic hypotension observed after flight? What are the effective countermeasures for this? |
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| 1 C2 C3 C4 C5 Critical Question | 9 | atrophy during either prolonged spaceflight or unloading? | 2 • 3 4 How is muscle metabolism regulated during normal activity and exercise, after acute and chronic unloaded states, and during recovery from unloading? | 2 * 3 4 What are the physiological similarities and | atrophy and fiber transformation and | transformation? How valid are ground-based models for studying the characteristics of | Space-flight-induced muscle changes? | | How completely and how well does injured muscle | | that are responsible for the control of muscle hypertrophy and atrophy, and what are the specific stimuli that are generated by exercise or disuse to signal increased or decreased protein | 2 * 4 What is the molecular in the molec | catabolic and synthetic rates of protein metabolism in unloaded muscles? |
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Critical Questions Listed by Deliverable from Volume 1 Section II

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| Delive Color Calcal Critical Question | What are the effects of altered levels of hormones and their receptors in regulating the physiology of unloaded muscle? | What is the link between mechanical activity (stress) and hormonal state in regulating protein turnover and gene expression and structure and function of muscle, as investigated by both ground-based and flight experiments? How can this information be used to integrate neuromuscluar and musculoskeletal models of mechanics and adaptation to develop countermeasure protocols? | What is the role of specific hormones, pharmacologic agents, and growth factors in regulating protein and gene expression in response to unloading? | What are the effects of unloading on the muscular intracellular and extracellular matrix? | What are the rate, extent, and time course of bone and connective tissue loss for different areas of the body during exposure to microgravity or simulated microgravity? How is the time course of regional tissue loss correlated with changes in the tissue stress and strain histories at the same site? To changes in regional microcirculation? To other regional and systemic factors? |
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| required for main tissue? How do mechanical loadii by space-flight? | required tissue? mechanic by space | required tissue? mechanic by space | required tissue? mechanic by space | tenance of bone and connective these processes interact with ng? Are these processes affected | N 22 C | N | n | n | | | ო | × | × | × | × | | × | | | | | - | |
| What are effective structure | | What are offective structure | What are effective structure | What are specific countermeasures that impact effectively upon bone and connective tissue structure and function? | 5c3 | - | 2 | N | ļ | - | η σ | × | × | × | × | | × | | + | += | + | | |
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| 4 What are changes because | What are changes because | What arr changes because | What are | What are histomorphological and architectural changes that occur in bone and connective tissue because of space-flight? | 5c7 3 | - 2 | \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | - 2 | ├ ── | - | m | × | × | × | 1 _× | 1 | × | | ~ | - | <u> </u> | - | |
| 4 How doe contribut formation required | How doe contribut formation required | How doe contribut formation required | How doe contribut ormation equired | How does mechanical stress and changes in stress 5 contribute to bone and connective tissue formation? Are stress and/or changes in stress required for continued structural integrity? | 508 | 8 | 0 | ļ - | - | - | е | × | × | × | × | × | × | | | - - | <u> </u> | - | |
| 4 What are the components of strain histories tissue developm How are these microgravity? | What are compone strain his tissue de How are microgra | What are compone strain his tissue de How are microgre | What are compone strain his issue de low are | critical characteristics or normal daily tissue stress and that regulate bone and connective nent, maintenance, and adaptation? characteristics affected by | 5c9 2 | 8 | N | - | - | V- | က | × | × | × | × | × | | | - | - | _ | | |

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| | | . <u>¥</u> | natterns and during activity compared to | te, | What are the bone and connective tissue markers of metabolism (protein synthesis, secretion, and degradation)? How can bone marker data be used to investigate and predict regional changes in bone | metabolism? Which endocrine-receptor perturbations modulate | tissue responsiveness to mechanical stresses: Which specific models predict bone and connective tissue structural transients during altered load | environments? What key elements of bone and connective tissue structural assembly impact the biomechanical | properties? Are there specific load histories that affect the macromolecular assembly of connective tissues? | What are specific signal transduction processes relevant to the modulation of structural molecules during attered load histories? |
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| | Critical | How are regional changes in bone an tissue related to regional changes in | How are neuromuscular activation patterns and musculoskeletal mechanics altered during activ (including exercise) in microgravity compared to | What are the patterns of in-vivo mechanical loading (e.g., tissue strain, stress, strain relations of the patronment of the property of the patronment of th | What are the bone and connective of metabolism (protein synthesis, degradation)? How can bone mark to investigate and predict regional | metabolism? Which endoc | tissue responsiveness to mechanical stresses: Which specific models predict bone and connectissue structural transients during altered load | environments? What key eleme structural asser | properties? Are there sp | ≱ ē ē |
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| C1 C2 C3 C4 C5 Critical Question | How do change is | stress (e.g., shear, stress) and/or electrical forces (piezoelectric and tissue streaming potentials) result in mechanisms that are associated with translational atterations in connective tissue structural proteins? | is cytokine production and response to cytokine by osteoblasts and osteoclasts affected by exposure to microgravity? | Are precursor cells of osteoblasts and osteoclasts affected by microgravity? | Do precursor bone cells respond to maturation stimuli in a microgravity environment as they do on earth? | Do osteoblast require gravity to function normally? If developed in microgravity will they function normally? | n the processing of signals ar canals or otolith organs that a? Do these changes take stibular nuclei, cerebellar related brainstem and cortical the time course of such correlate with space motion | the circuitry and signals in the vestibular brainstem that generate a |
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Critical Questions Listed by Deliverable from Volume 1 Section II Table 10

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| | Critical Question | What are the neural (morphophysiological) and neuroendocrine bases for motion sickness? What changes in neurotransmitters, neuroendocrine, or neurohumoral release can be correlated with space motion sickness? | What is the distribution of receptors for anti-motion sickness drugs in central vestibular pathways? | How does gaze stabilization change in altered gravitational states? What are the characteristics of gaze and eye-head coordination with varying visual, vestibular, and somatosensory inputs? | What is the most appropriate three-dimensional model of the angular and linear VOR and of central vestibular processing that will account for effections in ever movements in microgravity? | What are sensory inputs and coordination of muscular outcomes organized for generation of posture and locomotion before, during, and after | What are the pharmacology, physiology, and output 6b4 pathways that control the autonomic and endocrine outputs characteristic of motion sickness? | What models of sensory-motor transformation can be used to predict motor behavior best in altered pravitational states? | |
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| 4 | | 2 . | က | 4 | | Does a change in vestibular input lead to changes in 6c3 visual and auditory localization and multisensory spatial orientation? | 63 | 4 | | N ~ | <u>е</u> | , - | | | | | - × | _ | N | E . | 1 1 1 5 | 1 4 | 1 1 1 | | |
| 42 | | 5 | က | 4 | | What ground-based paradigms and models are most 6c4 effective in evaluating interactions of angular and linear acceleration, proprioception, somatosensory and visual inputs in determining orientation in a three-dimensional environment? How do these interactions change in altered gravity? | 40 | <u></u> | <u></u> | | ~ | 2 | 2 | × | × | × | × | × | | | - | - | | | |
| 42 | | 2 • | | 4 | | What processes explain the attered perceptions of 6c5 joint and body position in microgravity? | 5 2 | +- | m | 2 | က | 2 | ~ | × | × | | - × | × | | - | - | _ - | | | |
| 42 | | 2 * | 3 | | 5 | What pharmacological agents should be developed 7g7 and tested as prophylactic agents for low LET? | 7 3 | - | ~ | 2 | - | е | × | +× | + | + | × | × | | | - | 1- | | | |
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| Critical Question | How will at change the three-dimentications in the challenges and keratin in vivo), dien vivo, parimplantation osteoblasts | How long can single cells cope with changes in gravitational force without adverse results? Do these effects persist after return to unit gravity? | | What are the subcellular mechanisms whereby hair cells transduce acceleratory information, amplify it and bring about signal transmission? Is there a fundamental mechanism that is true across the animal kingdom? |
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| <u>.</u> | | What is the role of gravity in the regulation of circadian rhythms? — What are the effects of the absence of gravity on the generation, expression (period, phase, amplitude and/or waveform) and entrainment of circadian rhythms? — Is it at the synchronizing agent (zeitgeber)? — If not, is it necessary for the action of other synchronizing agents (light, exercise)? — What is the role of gravity in the ontogeny of circadian rhythms? — Is there a difference in the role of gravity across the phylogenetic scale? Single cells to complex organisms? — What is the gravity threshold for it actions in the regulation of circadian rhythms? Does this gravity threshold vary with the complexity of the organism? | How does gravity affect the regulation of metabolism,? Basal metabolic rate? Energy, metabolism, storage and substrate utilization? Body composition (fat and protein metabolism)? | What is the role of gravity in the regulation of the distribution, composition, and pressure of water/fluids in living systems from cells to complex organisms? How do these changes influence other homeostatic and regulatory mechanisms? | What is the role of gravity on thirst and fe behaviors (appetite, taste preference, and thresholds)? |
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| C2 C3 C4 C5 Critical Question | How does microgravity affect the function including feeding behaviors of gastrointestinal function? | What is the role of gravity on sensory thresholds (audition, visual, taste, pain)? How do endocrine, neurohumoral, and metabolic mechanisms influence this effect? | What role do endocrine and neural systems play in controlling/modifying adaptation to gravity? | What are the systemic, local, cellular, and subcellular mechanisms involved in adaptation to altered gravity especially bioenergetics and associated processes and cell-to-cell interactions? | What is the role of fluid redistribution in the response of the musculoskeletal system to altered gravity and how does gravity impact the homeostasis of fluid compartments within tissues? | What are the biochemical pathways responsible for synthesis, secretion, assembly, distribution, and degradation of structural and functional proteins in muscle in response to attered gravity? | What are the transduction mechanisms that couple mechanical stress to musculoskeletal mass and strength? What are the activation and force development processes of muscle and bone cells? | What signals the musculoskeletal adaptation to spaceflight? Are the signals the same as those found in biomechanical unloading on Earth? |
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| C2 C3 C4 C5 Critical Question | 1 = 5 | Do various risk factors(e.g., age, gender, species, strain (race), nutrition) modulate the musculoskeletal response to altered gravity? | What are the effects of intermittent and variable gravity fields on circadian rhythms, and how does this affect the use of artificial gravity as a countermeasure to microgravity? | What is the relationship between cardiovascular response and exposure to varying gravity levels (force, internal frequency, and time interval)? Is there a threshold? | What adaptive processes modify motor control systems? What is the dynamic range of adaptation of motor responses in altered states of gravity? | What are the long-term effects of prolonged space flight after return to 1 g? | How long do neutrophilia, lymphocytopenia, monocytopenia, eosinopenia, and reduced blastogenic responses persist after flight? | Does the extent of adaptation affect postflight orthostatic tolerance? |
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C1=Environmental Health C2=Countermeasures C3=Medical Care C4=Enabled Science C5=Basic Science; Cr=Criticality

1=Science readiness level 2=Technology readiness level 3= Schedule 4=Effort 5=Defined Sequence 6=Parallel/Alternative Path 7=Ground based 8=Space Labs 9=SSF 10=Centrifuge 11=Free Flyer 12=Lunar Base 13=Robotic Exporer 14=Other Requirements 15=Flight Validation Required 16=Facilities Sufficient 17=Community Sufficient 18=Attract New Community

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Table 10

Critical Questions Listed by Deliverable from Volume 1 Section

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| 3 • Following long-term space fligh or persistent consequences, eit harmful? As a corollary, are rehabilitative measures that she in the near-term (hours to day, (months to years) after flight? | Following long-ter or persistent cons harmful? As a c rehabilitative measin the near-term (months to years) | Following long-ter or persistent cons harmful? As a c rehabilitative meas in the near-term (months to years) | ollowing long-ter persistent cons armful? As a consultative measthe near-term (the near-term (the nears) | t, are there delayed ther beneficial or there appropriate ould be applied both s) and long-term | 3a12 | <u>ν</u> | 2 | ღ | - | е | ო | × | × | × | | × | | 0 | - | - | - |
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| 2 * 3 What are the opt readaptation to pmicrogravity? | What are the opt readaptation to p microgravity? | What are the opt readaptation to p microgravity? | What are the opt eadaptation to p | What are the optimal countermeasures for motor readaptation to partial-g or 1-g after adaptation to microgravity? | ; E99 | 2 | 2 | | 7 | - 10 | 2 | × | × | × | × | × | | | - | | -] |
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| If an on-board centrifuge is use countermeasure (physiological maintenance), will going from cause repeated maladaptions? | | If an on-board ce countermeasure maintenance), w | f an on-board ce countermeasure naintenance), w | ed as a system 1-g to microgravity | 6e2 | 2 | e e | | 2 | - | - | × | | × | | × | | | - | | - |

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| C5 Critical Question | Is musculoskeletal growth, development, and function compromised during spaceflight and can they readapt upon return to Earth? The structure and functional systems that should be examined carefully are: (1) the postural muscles, (2) muscle spindles, (3) weight/load-bearing bones and joints, (4) intervertebral discs, (5) the architecture of the connective tissues of the body and (6) musculoskeletal innervation. | Do we need artificial gravity countermeasures to protect from physiological deconditioning of a mission to Mars? | How should artificial gravity be applied in terms of g-load, rotation rate, and intermittent versus continuous exposure? | How does prolonged space flight affect behavior and group dynamics (including species, sex, and age differences)? | What procedures are needed for analyzing missions for their demands on human performance (e.g. task analytical techniques and models)? | What are the special performance requirements and capabilities and equipment requirements for extravehicular activity (EVA)? | What models can developed to describe the effects of fundamental behavioral stressers on mission performance? |
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Critical Questions Listed by Deliverable from Volume 1 Section II Table 10

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| Critical Question | What are the best psychophysiological correlates of effective performance variation in the space environment? In what way do physiological changes incurred in space affect task performance? | What are the effects of stress on crew and ground team performance and what method of detection and intervention strategies (e.g. selection, training, crew support) would prove effective? | What methods characterize the process of individual and team adaptation to stressors (e.g. isolation, confinement, and risk) inherent in space flight? | What are the factors that shape individual and team 1g3 motivation and the ability to cope effectively with environmental stress? | What are effective protocols for sustaining crews in case of loss of a crew member inflight, or loss of a family member or friend on earth? | What are the effects of exercise on circadian rhythms and sleep? What pharmacological and nonpharmacological (e.g. light, exercise) agents can be used to reset the human biological clock? What are the effects of routine administration of pharmacological agents in space on circadian rhythms and sleep? | What are the appropriate ground-based analogs for studying the effects of extreme environments on human circadian rhythms? |
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| C4 C5 Critical Question | What are appropriate research models for simulating the effects of the space environment? | What are the effects of non-gravity-related physical-chemical and psychological space-flight-induced stressors on circadian rhythms and sleep? | What roles do age and gender play? Is there a response of the circadian system to the space environment? | What are the effects of cephalad fluid shifts on circadian rhythms? | How does gravity interact with other environmental factors to control regulatory physiology and behavior? | What are the major human factors principles that govern optimal assignment of responsibilities between space crews and ground teams and among crew and team members? What ground-based organizations are required for effective support of flight crew performance on a Mars mission? | What are the critical elements and processes involved in decision- making by ground teams and space crews operating autonomously or in combination? | What are the critical characteristics of leaders that effect reciprocity and productivity of crews? What are the optimal crew command structures for a Mars mission? |
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| | sedures nd between | al characteristics and psychometric ng candidates for | g effective problem solving, ordination, and | int performance umans in a function of n, gravity field, | should be tation of essure in monary | andocrine Istatic Iervous ation, system, and | redict flight? |
| Critical Question | What are the optimal communication procedures for coordination among crew members and between ground and space crews? | What psychological and behavioral characteristics are exclusary? What behavioral and psychometric criteria should be used for selecting candidates for a Mars mission? | What are the protocols for training effective ground teams and space crews in problem solvinenhanced communication, crew coordination, and interpersonal dynamics? | What are the physical and cognisant performance capabilities and requirements of humans in different stages of space flight as a function of mission parameters, e.g. duration, gravity field, physical environment? | Which pulmonary life support procedures should be used for effective protection or resuscitation of crewmembers in the event of loss of pressure in the EVA suit or cabin, and for cardiopulmonary resuscitation and general anesthesia? | What are the effects of space-induced endocrine changes on the function of other homeostatic systems (e.g. cardiovascular, central nervous system, immune function, thermoregulation, reproductive system, gastrointestinal system, a energy metabolism)? | Are there in-vitro tests that reliably predict decreases in immune function in space flight? |
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Table 10 / Page 2

Table 10

Critical Questions Listed by Deliverable from Volume 1 Section II

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